A TREATISE ON PRIMARY GEOLOGY;

BEING

AN EXAMINATION,

BOTH PRACTICAL AND THEORETICAL,

OF

THE OLDER FORMATIONS.

BY

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Intellectus humanus in iis quæ semel placuerunt, (aut quia recepta sunt et credita, aut quia delectant,) alia etiam omnia trahit ad suffragationem et consensum cum illis: et licet major sit instantiarum vis et copia, quæ occurrunt in contrarium; tamen eas aut non observat, aut contemnit, aut distinguendo summovet et rejicit.—*Novum Organum.*

TO

THE REV. ADAM SEDGWICK,

F.R. & G.S.

PRESIDENT OF THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE,

&c. &c. &c.

AS A MARK OF

HIS GREAT ADMIRATION AND SINCERE ESTEEM,

THIS WORK

IS RESPECTFULLY DEDICATED,

BY

THE AUTHOR.

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CHAPTER I.

Introduction: — reasons for undertaking this work — the nature of its contents — its objects twofold. — The study of the primary rocks long neglected — beginning to attract more attention. — The proposed order of arrangement.

The discussion of geological opinions, which are professedly hypothetical, and which can only be expected to enjoy an ephemeral existence, in consequence of the rapidly progressive state of the science, may appear to many to be an unprofitable occupation of time, which might be better employed in the examination and description of the phenomena of nature. But it will, perhaps, be more generally admitted that such speculations are conducive to the welfare of the science, by promoting and directing various investigations, and by exciting the geologist to greater exertions during his toilsome excursions.

By such an admission, however, it is not intended to advocate the labours of the mere theorist, whose knowledge has been entirely derived from books; but, to contend for the utility of such theoretical views as have been deduced from practical experience.

Having, therefore, observed, during a geological survey of Cornwall, many facts which appeared to be incompatible with the prevailing theory, I was induced to publish them in the "Cornish Transactions," and to attempt their solution by another explanation.

It has been advanced, in reply, that the granitic formation of Cornwall may not be analogous to that of other countries: it has also been suggested, that I have greatly erred in supposing the circumstances of this narrow peninsula to be applicable to all granitic districts; and that a more extended knowledge would lead me to confess, with the peasant Tityrus,

> "Urbem, quam dicunt Romam, Melibœe, putavi
> Stultus ego huic nostræ similem."

This censure, however, has been expressed in the most courteous terms; and certainly the position into which I ventured, as an opponent of generally received principles, fairly exposed me to such reproof: but this would not have been so strongly called for, if the limits of the channel through which my dissent was made public had permitted me to enter more fully on the subject. Now, however, no such restraint can operate, and, by freely quoting the works of those geologists who have most carefully examined the primary rocks, I shall endeavour to show that the geological structure of Cornwall is similar to that of other granitic districts.

Having failed in my first attempt to induce geologists to enquire into the validity of these objections, — which indeed bear on the fundamental principles of the science, — I, in the next place, invited the geological section of the British Association at Cambridge to discuss this subject, being prepared to maintain my position, not only by reference to Cornwall, but also by arguments derived from the published descriptions of other countries. Circumstances, which need not be here mentioned, prevented this proposition from being then entertained; but it was appointed that the matter should be fully discussed at the succeeding annual meeting, which is to be held at Edinburgh during the present year.

In consequence of this resolution, I now publish an exposition of my objections to the Plutonic theory, with the intent that the members of the Association may clearly understand the grounds of dissent, and come prepared to examine into the merits of the question on an open and fair field. By thus freely disclosing to my opponents the plan of attack intended to be followed in the approaching discussion, my chance of success is certainly not augmented: but truth, not victory, is the object contemplated; and if my conclusions have been legitimately deduced from the facts brought forward, their value cannot be diminished by an exposure to the fullest scrutiny.

It may possibly be regarded as a mark of great presumption, in thus venturing to attack opinions which are advocated by the highest authorities: and it can only be urged in extenuation of such a prepossession against my labours, that geology is as yet in its infancy; and that its pursuit does not, like astronomy, and the more perfect mathematical sciences, require a great depth of learning and acumen in order to enable a zealous disciple to promote its advancement.

Appealing, therefore, to my long, and I trust not altogether unprofitable, examination of the primary rocks, I rely on the well known candour and liberality of the eminent men from whom I have presumed to differ; feeling convinced that, if I should substantiate any objection to their theory, they will rejoice that an error has been corrected.

In conducting the proposed enquiry, there are two objects which will demand attention: — First, the description of the primary rocks both of Cornwall and of other countries, in order to ascertain in what respects they are analogous to each other; and, in the next place, an examination whether the phenomena exhibited by these rocks are in accordance with the principles of the prevailing theory.

On this plan, the following pages will be nearly equally divided between a narration of facts and hypothetical speculations: — and the former part will lead to such lengthened preliminary details, as to constitute an essay on primary geology; which, so far from detracting from the interest of the work, may, perhaps, impart to it a more permanent value than it would otherwise possess. Indeed, without such an introduction, the succeeding theoretical discussion would not be generally understood: for the granitic formations have not been carefully studied by all the cultivators of geology during the last twenty years; and even now they attract little attention, as is clearly demonstrated by the brief and unsatisfactory manner in which they are sketched in the recent, and otherwise excellent, works of De la Beche and Lyell. Dr. Macculloch, indeed, during the early part of the period specified, continued to enrich this branch of the science with a vast body of facts, to which I am indebted for numerous and most important illustrations: but, with this exception, no geologist of note, in this country, has published any minute and descriptive details concerning the primary rocks; all have been absorbed in the pursuit of the wonderful and fascinating knowledge unfolded by the fossiliferous strata. This predilection in favour of a new study, which gave access to unexplored regions, abounding in valuable productions, is not surprising; but, now that time and successful researches have somewhat satiated the vehement curiosity at first excited, it may be hoped that the other department of the science will no longer be regarded as uninteresting or unfashionable; but that each will equally be the subject of active and patient investigations.

There is reason to expect that this desideratum is on the eve of being accomplished; for Professor Sedgwick, in his address to the Geological Society in 1830, pointed out and advocated the importance of the study of the older rocks. And he has also added example to precept: for some time past he has been, and is still, engaged in exploring the intermediate or transition rocks, the debateable land on the confines of the primary formations. Nor must it be forgotten, that De la Beche has been occupied during the last two years in the examination of Devonshire; so that the primary rocks must necessarily come under his observation: and that they will receive a careful investigation may be expected, not only from his known character, but also from the estimation in which he holds this department. "The inferior stratified rocks," he observes, "may not at first sight be so attractive as the contemplation of the varied forms of organic life, and the probable conditions under which it may have existed; but it will, nevertheless, be found equally, if not more, delightful as the enquirer obtains more certain results, from the investigation being conducted through the medium of the exact sciences." *

Under the circumstance, therefore, of the returning attention of geologists to this long neglected branch of the science, my labours may now meet with a more favourable reception than they would have some years ago, when the study of the granitic formations was regarded as an unprofitable pursuit, the riches of which had been exhausted. And it is hoped that the details here collected may prove instructive to the student, by conveying a more accurate idea of the nature of the primary rocks than he has, hitherto, been able to obtain: and they may not, perhaps, be altogether unacceptable even to the experienced geologist, as they may serve to call to his recollection, and to place in one point of view, many scattered and insulated facts, which can scarcely fail to appear more luminous by the concentration of their diverging and individually feeble rays into one narrow and well-defined focus.

It has always been kept in view as an important object, to preserve these details as free as possible from all hypothesis: but the language of the science is, in many instances, so engrafted and founded on theoretical speculations that it could not be always accomplished; for, in some cases, the published descriptions would not admit of translation into less exceptionable language without the risk of perverting the author's meaning, or of incurring the imputation of misrepresenting facts.

* Geological Manual, 8vo. p. 432.

In the arrangement of these details the following order has been adopted: —

1. A description of the various kinds of granitic rocks, and the modes in which they are associated together.

2. Of the primary schistose rocks, under the same relations.

3. Of the structure of the primary rocks.

4. Of the nature of the primary rocks, both granitic and schistose, at their junction with each other.

5. Of the modes in which these rocks are intermixed and connected together.

6. Of the mineral and metalliferous veins by which these rocks are traversed.

Having thus premised the nature of the arrangement, it is now proposed to enter on the subject without farther preface.

CHAPTER II.

DESCRIPTION OF THE GRANITIC ROCKS OF CORNWALL.

Definition of the term *primary* as here employed. — General aspect of primary districts. — The present nomenclature of the primary rocks defective. — The ternary compound of felspar, quartz, and mica, the type of granitic formations: its varieties. — Excess of felspar, and the accession of shorl, the characteristics of the granitic formation of Cornwall. — The different kinds of Cornish granite: shorl-rock, protogine, eurite, felsparite, and the quartzose varieties of these rocks, or quartz-rock. — These granitic rocks associated together, as alternating beds, as irregular-imbedded patches or masses, as veins, as elvans or dykes.

Before proceeding to describe the various primary formations, it is desirable to define in what sense the word *primary* is here employed; and this is the more necessary, since it has not only fallen into disrepute both with foreign and British geologists, but attempts have been lately made to erase it altogether from the nomenclature, as conveying an idea incompatible with the prevailing theory.

The term *primary*, in its original acceptation, is certainly very objectionable, inasmuch as it has a theoretical signification, which ought to be avoided in every classification: but the word *hypogene*, by which Lyell has proposed that it shall be superseded, is liable to the same objection; and the term *crystalline* schists, advanced by Boué, though free from this defect, is not more happy, because several igneous and sedimentary rocks have a similar characteristic.

For these reasons we have continued to use the word primary; but, at the same time, regret the want of such a term as would be generally applicable to rocks of this nature without implying any hypothesis. In the mean time, however, it is proposed, in the following pages, to consider as primary rocks the various kinds of granite, and all those crystalline and non-fossiliferous masses, both compact and schistose, which are usually associated together under different arrangements, and intimately connected by frequent mineral transitions.

This proposition may appear to some to be inadmissible, on the ground that the rocks thus brought together belong to several distinct geological epochs: but, admitting this view of the subject, (for, though it will be disputed hereafter, it is immaterial at present,) still these rocks constitute such a natural family, that they may be examined and described as such, independently of all theoretical considerations concerning the nature of their origin. Since this is a point that ought to be satisfactorily established, it may be stated, for the sake of the general reader, that Lyell admits that, "if we investigate a large portion of a continent which contains within it a lofty mountain range, we rarely fail to discover another class, very distinct from either the subaqueous deposits or volcanic rocks; and which we can neither assimilate to deposits such as are now accumulated in lakes or seas, nor to those generated by ordinary volcanic action." Again, he adds, that "nothing strictly analogous to these ancient formations can now be seen in the progress of formation on the habitable surface of the earth; nothing, at least, within the range of human observation." * Since these remarkable formations are so distinct from all other kinds of rocks, no great disadvantage can arise from our treating of them under the denomination of primary rocks; it being always remembered that this name is not used in a theoretical signification. Having offered this apology for the employment of a term so objectionable, we will now proceed to our task without farther preamble.

The primary rocks generally impart to a country a wild and desolate aspect: here and there, indeed, landscapes of great luxuriance and beauty present themselves; but the

* Principles of Geology, vol. iii. p. 10, 11.

most common feature is a wide expanse of barren hills, abounding in grand and romantic scenery. The character of such countries is more dependent on the granite than on any other member of the primary class.

"Granite is one of the most universal rocks, forming some of the highest and most remarkable chains of mountains. It is not, however, limited to such high ranges as the Himalaya or the Alps, or even to the much lower ridges of Britain; since it also occupies many extensive tracts of comparatively level land. This rock has been commonly supposed to be characterised by the pinnacled and serrated form of its mountains, such as the well-known summits of the Alps, and of the island of Arran: but this is not the case, for it assumes every variety of outline. The mountains about Loch Etive, in Scotland, have a simple conical form, which is particularly marked in Cruachan; the extensive ridge which surrounds the sources of the Dee, forming the loftiest tract of land in Britain, presents a series of heavy-rounded elevations; in Cornwall, in Galloway, and in Sutherland, it offers the same uninteresting aspect; while, in many parts of Aberdeenshire, it occupies the lowest grounds, presenting large tracts of level surface." *

When a granitic country is characterised by elevated and precipitous hills and mountains, its surface is covered with numerous detached rocks; diversified here and there with projecting tors or cairns of various fantastic forms, according to the nature of the rock, and of the corroding influence to which they have been subjected. Such tracts, whether they occupy a whole district or are confined to portions thereof, are generally barren, or, at best, they only afford a scanty pasture for cattle during the summer months, and supply the cottager with wild plants, and turf for fuel; but, wherever a granitic country is composed of undulating hills, with occasional level spots, though the latter are commonly marshy,

* Macculloch's System of Geology, vol. i. p. 54.

the former sometimes possess a good soil, adapted either for tillage or pasture.

The primary schistose districts which surround the granitic rocks partake of the same characters: they are, however, in general, more capable of cultivation; and their valleys find a better drainage in the rivers, by which they are frequently traversed.

When we take a bird's eye view of a primary country, the surface very commonly exhibits a system of valleys, which run parallel with the central ridge of granite; and these longitudinal valleys are intersected by others which cross them at right angles; and as the intermediate hills are more or less rounded, the surface of the country has an undulating appearance in both directions, which has been often and aptly compared to the waves of the sea; and the simile is farther appropriate, inasmuch as, when the curves of the hills are regular and gentle, or variously contorted and abrupt, they resemble the sea when agitated by the wind with different degrees of violence.

On the form of these two systems of valleys many features of the primary districts depend. Through them the rivers flow, seeking an outlet into the sea by the nearest continuous descent: sometimes they effect this along the longitudinal, at others, through the cross valleys, receiving tributary streams on either hand from the lateral valleys, or curved hollows, which they intersect. But very often the course of a river is diverted more than once from its original valley, in consequence of the concavity of a cross curve rising above its level, or that of the other system descending below this point, by which irregularity the stream flows along a more favourable drainage; and, not unfrequently, when both systems of valleys oppose like obstructions, the rivers, thus dammed up, are converted into lakes; which again obtain an outlet, or not, according to the positions of the adjacent concave curvatures of the intersecting ranges. In this manner, the course of a river, whilst within a primary region, is determined by the form of the surface; and thus it is that, whilst some streams are short and rapid, others, which at first run in parallel and adjacent valleys, are conducted by a long circuitous route, exhibiting rapid falls, or gliding slowly along, according to the nature of their channel.

The longitudinal valleys are the most extended, and often present a more gentle outline; whilst the transverse commonly form narrow and abrupt hollows, or gorges, in which the rock is exposed to view, affording to geologists opportunities for examination as favourable as any in Alpine regions.

Such is the external appearance of the primary rocks; and we now proceed to describe their mineral characters, dividing these rocks into two artificial classes, the granitic and schistose, in order to facilitate their description.

Under the head of granitic rocks it is proposed to comprise all those various compounds which are usually associated with common granite, being continuous therewith, and forming an integrant part of the same *unstratified* mass.

On account of this intimate association, it has become a pretty general practice to designate all these varieties of rock by the name of granite. They are certainly all geologically identical when they occur in the same mass; but, as will be seen hereafter, they are not confined to this position, and therefore their nomenclature ought not to be founded on a geological basis. This practice is also objectionable, inasmuch as it prevents the student from taking practical lessons in the book of nature until he has completed the course of theoretical instructions; and then it too frequently happens, that he can only make his observations according to the prescribed rules, and under a particular bias, prejudicial to impartial observations.

If a rock be designated according to its geological relations, its name must be liable to change, because the principles of the science are not as yet permanently established; besides, on this plan, in the examination of countries previously unexplored, too much depends on the correct judgment of the observer: but when a rock acquires a name from the nature of its composition, whether purely mineralogical or blended with organic remains, then this part of the science becomes perfectly descriptive, like the other branches of natural history; and much curious and accurate information may then be expected from travellers who are not accomplished geologists.

This subject of nomenclature will be entered on more fully hereafter, when the general reader will be better prepared to appreciate the importance of mineralogical distinctions among the primary rocks; and it is hoped that the geologist will admit that they are not frivolous, when it is shown that by their means some arrangements in the structure of the earth will be developed which otherwise could not have been detected.

In most of the lately published geological accounts of countries we look in vain for details concerning primary rocks: we sometimes, indeed, learn that such and such a district consists of granite, but cannot collect any information concerning its composition, or the manner in which its varieties are associated together. We are therefore left quite in the dark as to the nature of this rock; for the various kinds which may come under the designation of granite are not only exceedingly numerous, but have very frequently no resemblance whatever to the common variety so universally known by the name of granite.

This ought not to be. And Dr. Macculloch*, although he has so strongly advocated this method, admits, in his directions for conducting geological observations, that "a correct description of its mineral characters is necessary, as the varieties of this rock are highly interesting, especially under its passages into trap." Now, this trap is only a variety of that kind of granite which abounds with hornblende, the characteristic mineral of this rock in many parts of Scotland: and if the different forms of granite are deserving of remark when hornblende is present, surely they ought also to be

* System of Geology, vol. ii. p. 473.

noted when shorl characterises the rock, as in Cornwall; or when talc prevails, as in the Alps, in Corsica, and in some parts of Norway. In each of these instances, the *suite* of rocks of which the granitic range is composed is very different; and this variation is distinctly connected with the nature of the characteristic mineral.

This circumstance alone, therefore, independent of facts to be hereafter adduced, is sufficient to show, that geologists ought not to rest satisfied with stating that a country is composed of granite: it is, certainly, in descriptions very convenient to be able to denote in general terms that a country consists of granitic rocks; but this ought not to obviate the necessity of specifying the nature of the individuals of which this group is constituted.

These preliminary remarks may, perhaps, induce attention to the contents of this Chapter, which otherwise might be passed over as tedious details by those who have not interested themselves in the examination of primary rocks; but they will be found a necessary introduction to the right understanding of the phenomena to be hereafter discussed, and may enable the student to comprehend "those almost infinite variations in the composition of these rocks, which appear to set classification at defiance; but which, however perplexing at first sight, will, it is presumed, ultimately lead to an accurate knowledge of the nature of the granitic rocks."

Granite, in the common and original acceptation of the term, denotes a rock composed of felspar, quartz, and mica. It oftentimes contains, in addition to these, some other minerals; but those just enumerated are considered, in the following pages, as *essential* to true granite; and if either of them is wanting, the compound may then receive a distinct denomination.

These component minerals of granite, both essential and accidental, are united together by a confused crystallisation, not only mutually penetrating and interfering with each other, but sometimes the small crystals of one are completely enveloped in the large crystals of a different kind of mineral. And it is a very common occurrence for one, or even more, of these minerals to be developed in large crystals, in a granular basis of the whole, so as to constitute a porphyritic granite. This character is generally imparted by the felspar, and rarely by the quartz or mica.

When the crystalline minerals are united in moderate-sized granules, the rock may be called common granite, since it occurs more universally than any other kind: indeed there is, perhaps, no primitive range of any considerable extent in which it is altogether wanting. In the characteristic specimens of this variety the felspar is most abundant, and the quartz exceeds the mica: the respective proportions of these, however, are liable to great fluctuations. Other varieties of this rock, depending on the size of the component parts, may be noticed; which, relatively to the common, may be termed small and large grained: the former exhibits every degree of diminution, until the ingredients can scarcely be distinguished by the naked eye; and this kind, like the common, is of too frequent occurrence to need any particular references. The latter, or large-grained variety, however, when its minerals extend to any great size, is more rare: it is not to be found in Cornwall, but near Aberdeen in Scotland, and in Siberia. Each constituent attains a very large size, and is very crystalline, more particularly the mica, in Siberia, where it occurs in large hexagonal tables, easily separating into transparent laminæ or plates, which have been applied to economical purposes.

When either of these kinds of granite contains, in addition to the essential minerals, any other substance in such quantity as to alter the appearance of the rock, then it may be regarded as a distinct variety; but when the proportion is very small, the presence of the adventitious mineral may be overlooked in the classification: though this circumstance ought to be noticed, because, in all probability, it will be found to increase in importance in other parts of the same range.

Such are the ordinary varieties of *true* granite, rocks which are of such frequent occurrence, and for the most part in such general use, that they are familiar to the most cursory observer. So far, then, the nature of these granitic rocks cannot be mistaken: those that remain to be described are far more numerous, and more partially distributed, and can therefore only be found in certain localities. On this account it is proposed to describe the granitic rocks of several districts, by which means their history will be better developed, and the details be rendered more interesting.

In Cornwall the granitic rocks occur at the surface, in the form of eight insulated masses, four of which are of much greater extent than the others; each of these masses presents some peculiarities, but all of them contain several varieties of true granite.

The most general feature of the Cornish granite is the abundance of its felspar, which not only forms the greater part of this rock in the ordinary granular varieties, but is frequently superadded in the form of large porphyritic crystals, constituting no inconsiderable proportion of the whole mass. Shorl, however, is the characteristic mineral of this district; indeed it is seldom altogether absent from these granitic rocks for any extent, though it is often in such minute particles as to require a magnifying glass for its detection.

When shorl forms a portion of true granite, the rock may be sufficiently distinguished by the term shorlaceous granite; but when the shorl usurps the place of mica, or is combined only with quartz, then the compound requires a peculiar name: that of shorl-rock has been applied to some of its varieties, and it is proposed to use it here in a more extended sense.

Shorl-rock is sometimes composed of a crystalline granular mixture of felspar, quartz, and shorl; and this *granitic* shorl-rock, assuming various appearances, according to the size and proportion of its minerals, is generally associated with, and gradually passes into, the different kinds of true granite. On the other hand, it frequently, by the disappearance of the felspar, becomes perfect shorl-rock, a crystalline compound of quartz and shorl, which, like granite, exhibits many varieties, according to the size or predominance of either of its constituent parts. One form of this rock deserves very particular notice, not only on account of its association with its congeners, but also because it is of frequent occurrence amongst all the other kinds of granitic rocks. It consists of an intimate union of quartz and shorl, forming a *compact* shorl-rock, which sometimes has the external appearance of a hornblende-rock, but may be distinguished therefrom by its great brittleness. In the compact shorl-rock the quartz generally predominates, so much so that the shorl often seems only to act the part of a colouring mineral; and this rock is often seen accompanying quartz in alternating stripes of various sizes, from that of a line to a foot or more in thickness. These are sometimes straight, and sometimes curved, or even contorted, in as intricate figures as the agates; and not unfrequently the shorl, as the colouring ingredient, is so disposed, both in rounded and angular forms, as to impart to the mass the resemblance of a fragmentary rock.

The granitic rocks of Cornwall also present other kinds: the most important of these is that one which contains talc instead of mica; for its granitic variety is the source of the *china-stone* and *china-clay*, more than twelve thousand tons of which are annually exported for the use of the potteries.

This rock is a species of *protogine:* its talc is commonly in the state of small scales, exhibiting various tints of yellowish green. It assumes most of the forms which are common to the shorl-rock: all of them do not probably exist in Cornwall, but they occur in countries where this rock is more extensively developed.

The most common kinds of Cornish protogine depend on the size and proportion of their felspar, quartz, and talc: but sometimes this rock becomes quartzose, by the gradual loss of the felspar, analogous to the perfect shorl-rock, and in this state it forms the only protruding masses; for the granitic kinds are so prone to decay, that they are perfectly disintegrated for more than twenty feet beneath the surface. This quartzose protogine is, however, more commonly seen as loose boulders on the hills; and although now seldom found, they were probably more abundant formerly, as this stone enters pretty largely into the construction of churches and other ancient buildings in the neighbourhood.

It has already been stated, that the granular mixture of the true granite sometimes becomes so minute, that its constituents can scarcely be discerned by the naked eye. This variety frequently passes into such a fine granular homogeneous rock, that, even with the magnifying lens, we cannot detect the usual granitic minerals: it appears, indeed, to have passed, by the intimate blending of the quartz and felspar, into a variety of compact felspar, to which the name of *eurite* may be appropriately applied. This substance, however, is seldom perfectly pure, but forms a basis in which small granules of quartz and minute scales of mica are imbedded. It sometimes becomes porphyritic, by the presence of distinct crystals of felspar; in some places it also contains shorl or hornblende; and it not unfrequently happens that, towards the centre of a bed of eurite (by the increased size of the concretions of quartz, mica, and felspar), the basis disappears, and the rock becomes a perfect fine-grained granite.

This *euritic suite* of granitic rocks prevails in certain parts of Cornwall, while in other parts a similar series occurs, only the basis, instead of being fine, granular, and rather soft, as in the eurite, is a hard compact felspar; so that, although the composition of these rocks appears to be the same, their appearance is very dissimilar. It is proposed to call this genus *felsparite*, in order to distinguish it from the other granitic rocks. The species of felsparite arise from the nature and disposition of various minerals in the basis of this genus, as in the case of eurite. Of these, the porphyritic variety, arising from the presence of crystals of felspar, is of common occurrence, and very characteristic of this rock: it is the felspar porphyry of Macculloch and other geologists; but, as in this work the word porphyry is not used in a generic but a specific sense, it will be called porphyritic felsparite. This series of rocks not only passes at its centre into a fine-grained granite, like eurite, but also into a large-grained, and even a prophyritic granite. But the most interesting, and indeed the most conspicuous, circumstance to be noted concerning felsparite is the constant change in the nature of its basis, caused by the fluctuations in the proportions of the felspar and quartz which enter into its composition; for it assumes different characters according as one or other of these minerals predominates, exhibiting all the intermediate shades between a crystalline compact felspar, jasper, hornstone, iron-flint, and even quartz itself.

The description of the various kinds of Cornish granite must not be terminated without a few remarks on those varieties which are very quartzose, passing, indeed, very commonly into perfect quartz. These are confined, in a great measure, to the immediate vicinity of quartz-veins, which are sometimes metalliferous; and, in these instances, if the vein be of moderate dimensions, they would attract little attention; but when the veins are of a large size, or when an entire layer of granite is quartzose, then they would be pronounced by most geologists to be kinds of quartz-rock. When these quartzose varieties have been observed in other granitic countries, they have been regarded as superficial remains of strata which once covered the granite: but, as they are clearly not of this nature in Cornwall, it is desirable to bring them into one point of view, in order to justify our considering them, not as stratified rocks, but merely as varieties of granite.

In the case of common granite, the mass sometimes becomes so exceedingly quartzose, at the same time retaining its granitic aspect, that the rock is undoubtedly entitled to the term quartzose; as at St. Michael's Mount, at Kerris in Paul, and elsewhere. In some cases, however, the felspar gradually disappears; so that the rock consists only of quartz and mica (the latter, in some parts, bearing no inconsiderable proportion to the quartz), and has a perfectly granular character, like the *hyalomicte* of the French, the *greizen* of the Germans. One notable example of this occurs near Penzance, at Ludgvan: it has furnished an excellent building material, which is very common in the old houses of the town; but, unfortunately, the place whence it was obtained is no longer exposed to view. Its quartz is grey, and rather large-grained; its mica abundant, in small silvery scales.

Those varieties in which the mica is more sparing, and more intimately blended with the quartz, may be found on most of the elevated hills; more particularly at Roughtor, and Kitt Hill.

In like manner, the shorlaceous granites of the central and Land's End districts abound in quartzose varieties of this rock. When the felspar is wanting, shorl-rock, the equivalent of the micaceous hyalomicte, makes its appearance; and the shorl-rock is either granular or compact, according to the mode in which the component minerals are aggregated. The compact, either simply of a dark colour, or striped with quartz, is the most prevalent, and forms large courses, layers, or veins in the granite.

The talcose granite, or protogine, also possesses its quartzose varieties under similar circumstances as the true or micaceous granite, and more particularly that kind which results from the disappearance of the felspar; and is a granular compound, of a greenish colour. It is common in the china-stone quarries in the central district, where, however, it is generally associated with shorl; and it projects on the side of Tregonning Hill, in the form of tors, or perhaps, rather, of boulders or transported masses. It is well adapted for building, like the Ludgvan stone, cleaving well, and capable of being wrought with a chisel, as shown by its having been found to form the arches of the old chapel of Penzance, when it was lately pulled down; and the same stone may be also seen in the mother church at Madron, which is much more ancient. It is, therefore, very probable (since the granite, a few miles north of Penzance, contains protogine), that this talcose quartz-rock was obtained from erratic blocks, which have long since been consumed for building purposes.

The quartzose varieties of felsparite and eurite have been already noticed, as arising from the gradual predominance of silica over their felspathic ingredient; giving rise to hornstone, iron-flint, and many kinds of compact quartz-rock, known to the miner under the name of *capel.* This subject will be again reverted to, when it will be seen, that these, and other binary compounds, are of sufficient importance to require distinct appellations: for the present, we shall only farther observe, that, besides the evidence afforded by the cliff-sections, mining operations have also shown, that these quartzose compounds are not superficial, but are often persistent to great depths.

Thus we learn, that the granitic masses of Cornwall are not, as some have supposed them to be, composed of one kind of rock, uniform in its constitution, and uninteresting in its varieties, but are as complex in their composition as the stratified rocks; and, in their mineral transition into each other, afford as curious and instructive subjects for investigation: on this account, the utility of mineralogical distinctions is obvious; and it will be still more apparent, when we consider these granitic rocks hereafter, not only in their relations towards each other, but also towards the crystalline schists with which they are associated.

The granitic rocks are variously arranged among themselves. Sometimes each kind occupies a considerable space; or they alternate together in smaller masses, which are disposed in distinct and regular beds, highly inclined, and maintaining a parallel course. The nature of granitic countries will not admit of this arrangement being traced to any great extent; which, indeed, is likewise the case with the schistose rocks; for even their continuation is more frequently presumed than actually ascertained.

Even, however, when the characters of these rocks are well preserved over a given tract (that is, when they are distinctly granite, protogine, or felsparite, as above defined), yet a narrow inspection of any individual bed or layer will exhibit other kinds, in the form of veins, or insulated masses of various forms and dimensions.

The occurrence of a different granitic rock within another, arranged in patches or clusters around, as it were, certain centres of attraction, is of such common occurrence that it seldom arrests the attention; even when it does not consist of precisely the same ingredients as the main mass, differently combined as to proportions, or to the size of the component particles. But when these insulated compounds assume an elongated form, of greater or less regularity, then, under the name of veins, they have been considered more interesting, and have given occasion to much speculation concerning their origin.

These *granite-veins within granite*, as they have been called, are very numerous in the Land's End district; and are beautifully displayed in some parts of the cliffs near the Logan Rock and Lamorna Cove, more especially on the shore, where the rock is polished by the action of the waves.

Mr. Carne has enumerated, in the "Cornish Transactions," some instances of these veins in this locality, stating that they are of three kinds: — first, those which are of the same composition as the containing rock, but rather decomposed, and do not possess regular walls; secondly, those which only differ in containing large red-coloured crystals of felspar; and, thirdly, those veins which are compact and fine-grained, very different from the contiguous granite: they are numerous, and, when they meet, they do not traverse each other, but unite.*

Mr. Majendie, in noticing the veins and concretions of fine-grained granite and shorl-rock, in the porphyritic granite of the Logan Rock, remarks, that these, which on a slight view might be taken for fragments, are often penetrated by large crystals of felspar proceeding from the granite mass. †

Some examples of these granite-veins, on the same coast, have been described by Oeynhausen and Dechen. The granite of Tol-Pedn-Penwith, they observe, is of the common kind, with porphyritic twin crystals of felspar with shorl and pinite. Near the village of Sawah the fine-grained granite is like that of veins, consisting of quartz and red felspar, with a little mica, but a larger quantity of shorl: its position, however, is not that of a vein. The mass of the fine-grained rock continues of a fine texture to the distance of twenty feet from its junction with the large-grained; but, farther off, the constituent parts become larger and larger, and porphyritic crystals of felspar appear here and there; so that this rock gradually passes into the large-grained variety, both sorts of granite only differing from each other by their texture, and different state of crystallisation. Several granite-veins, exactly of the same composition as the fine-grained just described, abound in the cliff: one of these, in a little cove near the signal-station, is heaved nearly two feet by a quartz vein, as is also a shorl vein; but the latter traverses the granite-vein, without producing any heave. This granite-vein continues for a considerable distance into the sea; it is here divided into two branches. The large twin crystals of felspar they meet with are intersected by them, and heaved about half an inch.‡

When these granite-veins are of a large size they are termed *elvan-courses:* indeed, this is the only distinction be-

* Geol. Trans. Cornwall, vol. ii. p. 54. † Idem, vol. i. p. 29.

‡ Phil. Mag. and Annals, vol. v. p. 224.

tween these two forms of elongated masses of granitic rocks. In composition, these elvans are either shorl-rock, eurite, felsparite, or even varieties of fine-grained granite. They are particularly abundant in the Land's End district: and their presence is generally indicated by the abundance of tabular and very angular stones in the hedges and farm-buildings. These courses sometimes correspond or are parallel with the layers of common granite in which they are situated; but at other times they intersect these layers or beds, after the manner of the elvans in the schistose rocks. Notwithstanding, however, this apparent irregularity of arrangement, the elvans are connected on either side with the granite by the most intimate mineral gradations, or contain irregular portions or masses of the common granite, with which they also coalesce. Other marks of the close connection which subsists may be enumerated; such as the penetration of both rocks by felspar crystals, and similar appearances observed in granite veins: but one of the most important was described lately by the Rev. George Pigott, in a paper read at the last annual meeting of the Cornish Geological Society; viz. the continuation of the small veins or stripes of shorl through both granite and elvan; and also the extension of one of the parallel layers of granite itself through the elvan, at Pednmerer-mere, near the Logan Rock.

The alternation of soft and hard granite, so common in several parts of Cornwall, is of the same nature. The former frequently contains parallel contemporaneous veins of quartz and shorl, which abound in tin; and, when this is the case, the layer of granite containing the ore is considered by the miner as the lode. Sometimes, indeed, these veins are so numerous that it is necessary to excavate the whole of the rock, like the *stockworks* of the Germans; as at Carclaze mine, and the old workings of Beam mine, near St. Austle.

CHAPTER III.

THE GRANITIC ROCKS OF OTHER COUNTRIES COMPARED WITH THOSE OF CORNWALL.

Descriptions of these rocks neither numerous nor circumstantial. — The granite of Aberdeenshire characterised by its hornblende — its varieties.—The association of granite and porphyry in the mountain Cruachan, — and of granite and quartz-rock near Glen Tilt. — The granitic district of the eastern part of Ireland, — it abounds in quartz, — and is characterised by mica. — Granitic rocks of the Erzgebirge, at Freyberg, Altenberg, and Zinnwald. — Granite of the Hartz mountains also micaceous, — its nature doubtful, — interstratified with schistose rocks. — Remarks on the binary compounds of quartz with shorl, mica, or talc.

Having examined the granitic rocks of Cornwall, it is now proposed to turn our attention to those of other countries, in order to ascertain whether their constituent minerals are similarly aggregated together; and whether the masses resulting therefrom are subject to the same arrangements. The details, however, on this head are not so circumstantial as might be desired: this deficiency is attributable to two causes; first, to the indisposition of geologists to enter into mineralogical minutiæ, which they have hitherto considered in this country to be comparatively unimportant; and, secondly, to the want of such favourable opportunities for investigation as occur in the cliffs of Cornwall.

Notwithstanding the paucity of such descriptions, yet sufficient data may be gleaned for our purpose, which is to show, that the granitic rocks of other countries exhibit similar variations in their mineral composition, and similar associations as those of Cornwall.

We learn, from the excellent descriptions of the primary rocks of Scotland by Dr. Macculloch, that the granitic masses are analogous to those of Cornwall: they have not, indeed, the same composition, for hornblende, not shorl, is their characteristic mineral; but, with this difference, the resemblance will be found very great.

For example, if we examine the granitic range of Aberdeenshire, common or perfect granite will be found in the mountains at the sources of the Dee; as also the coarse-grained, fine-grained, and porphyritic varieties of the same rock: but hornblende is generally present, forming hornblendic granite. This mineral often takes the place of the mica altogether, giving rise to a perfect syenite, which exhibits numerous varieties, according to the size of the felspar, quartz, and hornblende, and the proportion in which these substances are united.

As in the case of shorl-rock in Cornwall, so in this syenite, one of the minerals sometimes disappears: in the former, this is the felspar; but in the latter, the quartz. And when this happens, the compound cannot be distinguished from some greenstones or traps, which are associated with the stratified rocks. The geologist just mentioned thus describes * the different kinds of this hornblende-rock: — "These rocks are fundamentally composed of felspar and hornblende; and according to the magnitude of their parts, and the relative proportions of these ingredients, the appearances of the specimens vary. In some rare instances, the crystals of hornblende are so large as to attain half an inch in length, although they are not defined in form; and as the felspar is commonly white, this variety forms beautiful specimens. From this size, the portions of each mineral vary in gradation; forming compounds, which resemble the coarser and finer greenstones. The hornblende is invariably black, but it is not always intermixed in an uniform manner with the felspar; some instances occurring in which, to the general indiscriminate mixture, are superadded large and distinct patches of irregular crystals, producing that appearance which, when it takes place in ordinary granite from a similar

* Quarterly Journal of Science and the Arts, vol. x. p. 36. *et seq.*

disposition in the felspar, has been called *porphyritic*. In general the felspar is white, and of the common kind; but, in the minuter states of intermixture, it has often a greenish hue, and so far loses its crystalline appearance as to resemble the ordinary compact felspar, which is more common in the greenstones of the trap family: this, however, is not easily determined, but I am inclined to believe that it does occur. When the mixture of the two minerals becomes minute, the rock is no longer distinguishable from ordinary basalt: and in some specimens, it even appears that the felspar is at length excluded; so that there remains nothing but that compact, yet minutely granular aggregation of hornblende, which, according to some mineralogists, constitutes the only genuine basalt. And it must also be observed that, among rocks of this character, some specimens cannot be distinguished from the black clay-stones, in which the peculiar lustre of hornblende is absent; and they are soft, with an earthy fracture."

From this statement we learn, that hornblende acts as important a part as shorl, giving rise to as many varieties of granitic rocks: and this is not the only analogy between the granite of Scotland and Cornwall, for other kinds of primary unstratified rocks are to be found in the former country. Of these none are more extensively diffused than the different species of porphyry, which are subject to the same mutations as those of Cornwall already described, and appear to have a similar composition, more especially their bases, which are only varieties of compact felspar assuming different characters, as its siliceous element varies in proportion.

The vicinity of Loch Etive also particularly abounds in porphyry, according to Macculloch; and its nature is well exemplified in the following extract from the same author: —

"The northern side of Cruachan * presents a range of nearly perpendicular precipices, extending many hundred feet down the mountain. This section shows that the mass of the

* Geol. Trans., vol. iv. p. 121. *et seq.*

mountain consists of granite, which is composed of a very equal mixture of reddish felspar and white quartz, with very little mica, nearly resembling the granite of Cairn Gorm. The granite is traversed by veins or courses of porphyry, varying from three or four feet to more than fifty in breadth: these are all very erect, and, in a general view, appear to be perpendicular; and are so numerous, that they form a considerable portion of the mountain. This porphyry is of various colours and composition; its basis consists of that substance called compact felspar, and its imbedded minerals are commonly felspar and hornblende; and, according to the proportion and the manner in which these are severally united, the porphyry assumes a great variety of aspects. Thus, by an uniform mixture of the basis and hornblende, the transition from perfect porphyry into greenstone is effected; and this greenstone sometimes resembles well-characterised basalt. Specimens of the junction between granite and this kind of basalt may be here obtained in great variety and abundance: the line of junction is, in all cases, clear and well defined; but does not admit of ready separation, even after long exposure to weather."

Thus we learn that, in Scotland as in Cornwall, the granitic rocks traverse the main mass of granite, in regular beds, veins, or courses, which only differ from each other in size: and that these pass into each other, and into the characteristic granite of the district, by the most gradual mineral transitions, so that it is not easy to detach one from the other.

In some parts of the granitic ranges of Scotland, quartz so predominates in the composition of the rock, that it deserves particular notice.

When this is not accompanied by the displacement of either of the other ingredients, it may be considered merely as a quartzose variety of granite; but very often it is only associated with felspar or mica, and in many instances both of these minerals are wanting.

These forms of granite have received distinct names from the French geologists; but Dr. Macculloch regards them all as quartz-rock. Thus, in his account of Glen Tilt, he observes, that the quartz-rock associated with the granite is of a compact and somewhat transparent quartz, containing irregular grains of felspar: it breaks in a flaky manner, and appears to consist of beds which extend along the granitic ridge to Grianan, in a north-easterly direction, and dipping to the westward of north. The granite in this situation is grey, and shows a slight tendency to a foliated structure in the vicinity of quartz-rock; so that these rocks appear to pass into each other. These beds of quartz-rock occur in many parts of the granitic range, so that it has the appearance of alternating with granite.* Macculloch thinks that these beds of quartz-rock are only superficial and detached portions of the stratified rocks superimposed on the granite; but it is more probable that they are members of the granitic rocks: for analogous rocks are decidedly so in Cornwall; and in Ireland they appear to be of the same nature, as will be immediately seen in Mr. Weaver's description of the granitic rocks of the eastern part of that country.

We are informed by this experienced geologist, that the large tract of granite stretching from the south side of the Bay of Dublin to Blackstairs and Brandon, about twenty miles north of Waterford, is full fifty-nine miles in length, and is in general remarkably pure, and free from minerals not essential to the composition of this rock: its felspar is commonly of a clear beautiful white, or slightly tinged with yellow or grey, very rarely flesh-coloured; its quartz is mostly grey, and its mica greyish-white, inclining to brown or black. This granite varies much in the size of its grain. The finest-grained variety occurs on the northern foot of Cadeen: it is remarkably close and firm in texture, appearing almost compact: it is accompanied, however, with a coarser-grained kind, with which it appears to alternate in layers, as may be

* Geol. Trans., vol. iii. p. 296. *et seq.*

seen in the brook which flows down the northern face of the mountain. This rock is not unfrequently porphyritic; in almost every glen the felspar crystals may be seen, two or three inches in length, inlaid in a small-grained base. But there is another variety of granite, which occurs in many parts of this tract, and requires more particular attention. "The eastern side of Eagle Hill, for example, corresponds with the usual granite of the country in the size of its grain and proportion of its ingredients; but on its summit, which forms an abrupt face to the north, quartz appears as the principal constituent, affecting a considerable variety of aspect. On the western side are great masses and blocks of pure white compact quartz, and lower down on that side is the quartz rock itself: on the south, again, the face of the rock is bared, and the granite here appears to be mostly composed of quartz; the prevalence of which becomes still more striking in the loose blocks, the felspar having decayed, and left a singularly connected tissue of quartz, exhibiting amorphous masses, veins, and ramifications."*

"In the southern part of this granitic district the granite is not immediately surrounded by mica-slate, but clay-slate; and the granite of the hills, extending from Conna Mountain to Crogan Kinshela, of the eastern bank of the Avonmore, of West Aston, of Kilmancanna Hill, and of the low rocky ridge called Carrigmore, which proceeds eastward, and is connected with the Dunganstown range, possesses characters different from those of the granite of other parts of this tract. Quartz, comparatively speaking, seldom appears in it; felspar and mica are the prevailing ingredients, sometimes the one and sometimes the other predominating. The felspar is usually of a yellowish or greyish white, unless when coloured greenish by mica; which mineral approaches sometimes to chlorite on the one hand, or to hornblende on the other. The felspar and mica are sometimes so intimately incor-

* Geol. Trans., vol. v. p. 132. *et seq.*

porated as to constitute an apparently homogeneous mass, much resembling some varieties of trap; and in other places it verges towards clay-slate in aspect and texture, as at West Aston and Rockstown. This granite acquires also, in some instances, a syenitic character, containing small crystals of hornblende, as in Carrigmore; and, in the western end of the Dunganstown range, it passes into true felspar porphyry, exhibiting a fine granular or compact ash-grey base of felspar, in which are inlaid small brilliant crystals of hornblende and glassy felspar.* There are few parts of this granitic region in which shorl, tourmaline, and garnets may not be casually found, but it is only casually, and in such small proportion that they must be considered as merely adventitious."

Thus we learn, that mica is the characteristic mineral of this part of Ireland; so that the granitic rocks are, in a great measure, constituted of varieties of true granite. The peculiar kind of rock accompanying these, in the southern portion of this district, appears to be a kind of eurite; for the descriptions of Mr. Weaver very accurately correspond with the Cornish species of this rock.

The association of these varieties in irregular and alternating beds, is also another analogy between this mass of granite and that of Cornwall; and we must not omit to mention another circumstance, which furnishes an additional feature of resemblance. "The granite, in the east of Ireland," says Mr. Weaver, "abounds in contemporaneous veins of granite, and also of quartz; which, however, are not quite so frequent. The former vary from the smallest to a very large grain, and in width from that of a thread to two feet. There is no glen, in which the rock is at all denuded, in which they may not be studied to advantage, and nowhere more so than among the sublime scenery of Glendalough. At the head of the glen the granite forms mural precipices, in which may be seen numerous veins of granite and quartz, several of which

* Geol. Trans., vol. v. pp. 168, 169.

range parallel to each other in a north and south direction; while these are frequently crossed under various angles by others, which sometimes produce a heave or throw in the traversed veins. They sometimes occur so numerously in a narrow compass as almost to resemble a kind of net-work: the position of these veins is generally vertical." *

The granitic rocks of Saxony cannot fail to interest the geologist, as the field in which Werner obtained no inconsiderable portion of his knowledge on this subject; but these rocks cannot be satisfactorily described independent of the primary schists with which they are associated. Indeed, this is the case with all the patches of granite, not only in the north of Europe, but in every other country. In conformity, however, with the plan of this work, and with the general opinion that the granitic and schistose rocks are of a very different nature, a brief description of the granite of the Erzgebirge will be attempted.

In this mountain chain the granite is not of great extent, only occurring in small patches near Freyberg and Altenberg, on the eastern side; and on the west, near Schwartzenberg, it forms small hills, the summits of which are rounded, and of little elevation.

At Freyberg this rock is fine-grained, and composed of grey or yellowish felspar, greyish quartz, and brown mica, in nearly equal proportions, and without the admixture of any other mineral. Near Altenberg the granite is similar, but, in some parts, contains large crystals of felspar. In the district of Schneeberg the granite is large-grained, and assumes various appearances, according to the size of the felspar crystals, which oftentimes impart a porphyritic character; in some places it decomposes very readily into porcelain-clay, and in others it contains much black shorl, crystallised or in nodules, and is traversed by granite veins, which are fine-grained, and, near Schorlau, are metalliferous, containing arsenical pyrites and sulphuret of molybdena. At

* Geol. Trans., vol. v. p. 136.

Zinnwald the entire hill is composed of granite and quartz-rock, disposed in regular alternating beds. The granite is fine-grained, and consists of felspar, quartz, and mica, all of which are white: it is, however, rarely found in a perfect, unaltered state, and that only near the centre of its beds: more commonly the mica passes into talc, and its felspar is decomposed into kaolin. These granitic beds vary from three to ten fathoms in thickness, and do not contain a trace of tin ore. The quartz-rock is of two kinds: the one is nearly pure quartz, grey, crystalline, with a greasy aspect, containing disseminated scales of mica, and crystals of wolfram and oxide of tin; the other, the *greisen* of the Germans, and *hyalomicte* of the French, is a granitic mixture of grey, crystalline quartz and argentine mica in large scales. Its beds are as thick as those of the granite: they contain disseminated masses of quartz and of granite, and abound in oxide of tin. The alternating beds of these rocks are inclined at angles varying from 15° to 20°. The beds of compact quartz-rock are commonly enveloped in those of the granitic variety, and thus alternate with the beds of granite: on the one hand, the granitic quartz-rock passes into the compact, by an augmentation in the size of the quartz grains, and by the coalescence of the mica into larger scales, and its diminution in quantity; and, on the other hand, it becomes finer grained, and graduates into the granite.*

This short sketch shows that the granite in the Erzgebirge, as in Cornwall, is disposed in detached and insulated masses, and that these likewise do not possess the same mineral composition. In the next place we learn, that the different rocks of which these masses are composed also affect a similar arrangement in beds which sometimes alternate; and it is worthy of remark, that in the granite of Zinnwald, which decomposes into *china-clay*, talc, not mica, is the characteristic mineral, — which is precisely the condition of the granite in Cornwall wherever this substance abounds. The nature of

* Annales des Mines, tomes 8. et 9.

the primary slates in this part of Saxony, and the manner in which they are connected with the granitic rocks, will be considered in another Chapter.

In the most extensive primary districts of Europe, however, the granite is not disposed in such rounded and insulated masses, but is more or less elongated, so that, when viewed on the large scale, it has the appearance of immense beds, interstratified with the schistose rocks; under these circumstances, it is now generally regarded, not as true granite, but as granitic varieties of the strata with which they are associated. This point will be discussed hereafter; we shall only now observe, that the most eminent geologists have differed on this subject; some contending, that these granitic beds, having the same physical and mineral characters as granite, are perfect and veritable granite, whilst others have maintained the view just given; thus, the immense granitic masses of Sweden and Norway have been by some pronounced to be true granite, whilst by others they have been denominated granitic gneiss, because smaller layers of the same rock are interstratified with, or completely enveloped in, the gneiss.

For similar reasons, most geologists assert that the granitic rocks of the Hartz mountains are members of the stratified rocks, or intruded masses of a more recent origin, because they, in some cases, alternate together, and also with crystalline schists, which gradually pass into the greywacké formation: we will, therefore, select this example for a description of this kind of granite, waiving all theoretical considerations for the present.

Several of the principal summits of the Hartz are crowned with granite, which exhibits the ordinary appearance of this rock, being traversed by three systems of fissures, one parallel to the horizon, and the others perpendicular, so as to divide the mass into cuboidal blocks, the solid angles of which have been rounded by the action of atmospheric agents. The granite is composed of the common ingredients, — felspar, quartz, and mica, — sometimes the felspar, and at others the quartz predominating; and it assumes various aspects, according to the size of its crystalline concretions. In ascending the valley of the Ilse, about a league from Ilsenburg, bare escarpments of granite present themselves, which appear to belong to beds of granite situated in the midst of a different kind of rock, which, being less durable, has been removed by the eroding influence of existing causes.

At Rosstrapp, on the eastern extremity of the Hartz, the granite is disposed in regular beds, with a general inclination towards the east; and these beds appear to alternate with quartz-rock, greenstone, schist, and a variety of mica-slate. On the northern side of the Hartz, at Adenberg, M. Bonnard saw a bed of granite distinctly enclosed in strata of quartz-rock and schistose jasper, of which the mountain is composed. And on the north-western side of the Brocken, several beds of granite alternate with greenstone: the latter rock is not perfectly stratified, but the beds of the former clearly run north and south, dipping towards the east.*

It is difficult, however, to separate the description of the granite from that of the schistose rocks by which it is accompanied, when they are associated in alternating beds: the details concerning the granite of Norway and the Alps will be found in another Chapter.

In concluding these brief details concerning the granitic rocks, we will only observe, in addition to the remarks which have been incidentally made, that a comparison of the granitic formation of Cornwall with that of other countries shows, that some compounds that are of rare and limited occurrence in the former, are developed elsewhere into extensive masses; as in the instances of the binary compounds of quartz and mica, and quartz and talc: and, *vice versâ*, the porphyritic granites and porcelainous protogine, sparingly scattered in other countries, are abundant in Cornwall, as are likewise, in a still greater degree, the shorlaceous varieties of granite, and the

* Annales des Mines, tom. vii. p. 44. *et seq.*

binary combination of quartz and shorl; — facts which point out to us that all well-marked compounds of distinct minerals ought to be distinguished by appropriate names, although they may be only known to exist in small quantities. The above specified binary compounds are as much entitled to distinct names as shorl-rock: if they be not required in the one case, neither is it necessary in the other; so that the terms shorl-rock, hornblende-rock, and others, should be expunged from the geological nomenclature, if this view be persisted in. If the knowledge of the primary rocks be a study worth pursuing, a mineralogical classification must be ultimatelv adopted; for, accurate details concerning their transitions into each other, and their modes of association, cannot be given on the present system. This topic will be reverted to; but in passing we cannot help seizing every opportunity to urge the necessity of this reformation, being firmly convinced that no measure will tend more to promote the progress of this department of the science.

CHAPTER IV.

DESCRIPTION OF THE PRIMARY SCHISTOSE GROUP OF CORNWALL.

The division of the primary rocks into stratified and unstratified objectionable. — Proposed to divide them into granitic and schistose groups, — only an artificial arrangement, to facilitate description. — Primary slates enumerated. — Schistose group of Cornwall. — Consists of two series, the porphyritic and the calcareous. — Definition of these series. — The slates next the granite variously named by Geologists. — They are of a peculiar nature. — Of two kinds, — one bounding the eastern, the other the western granite. — They pass into other kinds of slate. — The nature of this transition. — Greenstone, Actynolite-rock, Chlorite-rock, and the Magnesian rocks, Talc-schist, Serpentine, and Euphotide, described. — Remarks on the quartzose varieties of all these rocks, commonly called quartz-rock. — Nature and position of the granitic rocks or *elvans,* in the schistose group of Cornwall.

The primary rocks have been divided into stratified and unstratified; the latter comprising the various granitic rocks, which generally occur in large insulated clusters, and have a compact and massive structure; the former denoting those non-fossiliferous rocks which surround, and are intimately connected with the granite, and are very commonly distinguished by a slaty or schistose texture.

It will be found, however, that this division is perfectly arbitrary; for both stratified and unstratified rocks are so intermixed in their associations, that it is sometimes impossible to decide to which of these classes a rock, under examination, belongs: in order, therefore, in some measure, to avoid this confusion, the primary rocks will, in the following pages, be supposed to consist of granitic and schistose groups; only understanding by this division, that in the one granites, and in the other slates predominate; and it must not be forgotten that this is an artificial, not a natural arrangement, merely to facilitate description.

The rocks which immediately surround the insulated masses and ranges of granite, are very numerous; and although they are generally schistose, they are sometimes massive, and in their structure very similar to the granitic. These circumstances, however, will come under consideration hereafter; at present, our object is to obtain a knowledge of the composition and internal appearance of the individuals of the schistose group.

The primary slates, which have been longest known, and most frequently described, are gneiss, mica-slate, and clay-slate; in many places they follow each other in this order; and thus they were observed by Werner in Saxony and Bohemia; and it was therefore for a long time considered as the only and true order of succession.

A more extended experience, however, has not only shown that granite may be in immediate contact with either of these rocks, but also that there are many other primary slates, which, in like manner, are not subject to any fixed laws in the manner of their association. For our knowledge on this subject we are more particularly indebted to Macculloch, and the French geologists.

The following are the principal additions which have been made to the primary slates of Werner: viz., quartz-rock, actynolite, hornblende, shorl, chlorite, and talc schists, and steaschist; and in the 4th volume of the Cornish Geological Transactions some others have been proposed; so that it may be safely predicted, that as our knowledge increases, this catalogue will be extended.

In describing the various schistose groups, that of Cornwall will in the first place demand our attention. It may be divided into two series, the porphyritic and the calcareous; the former including those rocks which occur next the granite, and contain porphyries and other granitic rocks in the form of regular beds or *elvan-courses*, and which abound in veins of tin and copper ores; the latter, comprising those rocks which are more or less remote from the granite, contain no *elvans*, but abound much more in greenstone, especially its obscurer varieties, and in dark-coloured limestones; sparingly metalliferous, containing no tin, but productive of lead and antimony; and lastly, possessing occasionally organic remains.

Most of the rocks of the calcareous series appear to be referrible to the older portion of that class which is intermediate between the primary and the secondary, commonly known by the name of *transition;* a class of Werner's system which for many years had fallen into disuse, but has been lately revived on account of its convenience.

The individuals of this calcareous series will not be treated of in this place, with the exception of the magnesian rocks, serpentine, euphotide, and talc-schist, which immediately follow the porphyritic series.

The rock in contact with granite in Cornwall has been usually called argillaceous schist, or clay-slate. Dr. Berger, and after him many other geologists, have termed it greywacké; but, as Professor Mohs has very justly observed, it has no resemblance to this rock: some have adopted the word *killas,* from the miners, to denote this kind of slate, but have used it more vaguely than even it is done provincially; for even the miners acknowledge that some important varieties of this rock are not true *killas,* but a *kind of elvany killas.* The remarks of the late Rev. J. J. Conybeare are very appropriate:—"The common *killas,*" he observes, "after much question as to its being a variety of greywacké, which, if that term has any definite meaning, it unquestionably is not, has been at last admitted on all hands to be a genuine clay-slate; but this appellation, perhaps, after all, does not convey a much clearer notion of the real nature and constitution of the rocks included under it, than the repudiated greywacké." In fact, no term has been more misapplied than that of clay-slate; and its application has been general to all fine slaty rocks, no matter to what member of the primary slates they belong, or, indeed, whether they occur in the transition or secondary classes. In Cornwall, for instance, there are at least a dozen kinds of rocks that are very fissile, all of which have been indiscriminately called clay-slate, notwithstanding they sensibly differ from each other in their external and physical characters, and are respectively associated with distinct *suites* of rocks.

These differences of opinion have arisen from geologists having examined the Cornish slates in too cursory a manner. A more careful scrutiny would have shown that the rock adjoining the granite is neither greywacké nor clay-slate, but a rock *sui generis.* It is not meant to assert that this rock is not analogous to any of the innumerable varieties of rocks in other countries, which have been termed clay-slate; but that it does not correspond with clay-slate, in the ordinary acceptation of this term.

The rock adjacent to the granite in the western part of Cornwall, in which most of the productive mines are situated, is of a different nature from that similarly placed in the eastern part of the county; and it is worthy of remark, that the latter not only abounds less in metals, but is also associated with rocks different from those which occur in the former: the distinction of these is therefore important in an economical, as well as a scientific point of view. The former slate appears to be nearly allied to the thonschiefer of Johanngeorgenstadt: the latter, to the clay-slate described by Mr. Weaver, as occurring in the southern part of the granitic range in the east of Ireland.

Before attempting to show the composition of the Cornish slates, now under consideration, it will be well to describe their respective appearance: and, until geologists have determined their true nature, and agreed on distinctive appellations, the terms *cornubianite* and *proteolite*, proposed in the Cornish Transactions, may, for the present, be admitted, in order to avoid needless repetitions.

Cornubianite, the rock most abundant in the western part of Cornwall, exhibits various shades of dark blue and purple, sometimes of an uniform colour, but occasionally with dark stripes, spots, or patches, on a light blue base: it varies from hard to very hard; and breaks, though not easily, into thick plates full of joints; its surface is often spangled with a micaceous mineral, the parallel arrangement of which imparts to the mass a laminated structure: on decomposition, it becomes much more schistose, and of a dirty yellowish white colour.

Proteolite, as its name is intended to indicate, assumes a great variety of forms. In colour it does not much differ from the rock just described, but its tints are generally much lighter; indeed, its original colour is not often met with, for, owing to the tendency of this rock to undergo a partial decomposition, becoming earthy and argillaceous, it is generally found of a yellowish or very pale brown colour. It is much softer than cornubianite, and its hardest kind, instead of possessing the fine compact texture of that rock, is always more or less arenaceous. Its species are much more schistose; its composition is, for the most part, pretty uniform; sometimes, however, a shining mineral is present, in minute spots and scales, and in one instance the whole basis is shining and glossy, approaching very near to mica-slate.

Both of these slates appear to be principally composed of compact felspar, which is probably a compound, as already stated, of felspar and quartz in various proportions:—in cornubianite, this substance has an uniform massive texture; in proteolite it is finely granular. And, as the felspar or quartz predominates in the compact felspar basis, so these rocks exhibit different degrees of hardness, and other properties characteristic of the prevailing constituent. By these fluctuations in the composition of the basis, we can easily comprehend how these rocks sometimes contain beds of pure compact felspar, at others, beds which are entirely quartzose. The colouring or accessary mineral of these slates is not always obvious, but it appears to be either mica or shorl, or some intermediate substance.

It may be enquired, how can this be ascertained? The nature of the colouring mineral can only be proved in this manner. The slates in question, and indeed all the primary slates of Cornwall, form distinct suites or genera: some of the members or beds of each genus are schistose, and others compact; in the latter the basis is very frequently pure, and the colouring mineral is aggregated into either particles, scales, crystals, or such a body that its nature can be detected; and from these compact or crystalline beds, there is a gradual and almost imperceptible passage into the perfect slate, so that it appears to be a justifiable conclusion, that both the compact and schistose beds have the same composition.

Thus nature, as it were, proffers her own analysis to assist us in our researches, by giving us an insight into the constitution of rocks, in which the elementary minerals are so blended as to present only a homogeneous mass.

If this view of the subject be correct, we learn that cornubianite and proteolite are both composed of felspar, quartz, and mica, shorl, or an analogous mineral; that is, of precisely the same ingredients as granite. Mr. Hawkins, many years ago, appears to have entertained a similar opinion, for he suggested "that the common *killas* is an intimate mixture of quartz with mica, talc, chlorite, and perhaps, in some instances, with felspar." There can, however, be little doubt of the presence of the last-mentioned mineral; for, as in the case of granite, it generally constitutes by far the greater part of the mass.

After what has been now said, the nature of the remaining schistose rocks of the porphyritic series will be easily understood, since they have all a basis of compact felspar, united with hornblende, actynolite, or chlorite.

All these rocks appear to pass gradually into each other; and these transitions are not only effected by the variations in the composition of the compact felspar basis, but the accessary minerals themselves appear to be subject to similar changes, mutually passing into each other, giving rise to intermediate substances, which, if they be definite compounds, have not been hitherto described: it is more probable, however, that they are intimate mixtures of one or more of these minerals.

Several instances will be adduced hereafter, which show that mica, shorl, hornblende, and these analogous minerals, do graduate into each other; and as this is a subject of great importance, and is indispensable to a right understanding of the primary rocks, it ought to be particularly impressed on the mind of the student. "To the geologist," observes the Rev. J. J. Conybeare, "who seeks the aid of mineralogy and chemistry, examples of this intimate penetration of one simple mineral by another (so as, in many cases, to alter very considerably the external and empirical characters of that which yet predominates), must be familiar. Many subordinate beds of the earlier greenstone formation exhibit every stage of a similar phenomenon; and an accurate examination would probably show, that most of the substances named petrosilex, corneene, saussurite, jade, and even flinty slate, are, in fact, only admixtures of this nature, in which felspar, varying from its more compact and semitransparent, to its earthy and granular form, is uniformly and intimately penetrated by some variety or other of hornblende, of diallage, and occasionally, perhaps, of other minerals, which (as hypersthene) enter more sparingly into the composition of rock masses. Such admixtures can be properly studied only in those endless suites of specimens which Nature herself preserves, and presents *in situ.* The subject is an interesting one, and well deserves closer attention and investigation than it has yet met with." *

It is a very common opinion among geologists, that the almost endless varieties of primary rocks, produced by these mineral transitions, embarrass the investigation of this department of the science, and set classification utterly at defiance. But a more enlarged knowledge of this subject will probably prove, that this frequent passage of one rock

* Annals of Philosophy. New Series, vol. vi.

into another, so far from creating confusion, may form the groundwork of a systematic arrangement. We are sometimes apt to forget, that the deviations from our most approved systems are not indications of irregularities in the works of nature, but proofs of our imperfect knowledge; and, instead, therefore, of attempting to reduce all things within the bounds of our limited views, we ought rather to enlarge, or even alter our opinions, so as to adapt them to the phenomena of the Creation. Such a line of conduct has been often and very successfully followed; and, in the case now under consideration, it would probably be found advantageous, though it could not be expected that the application of this principle would, in the first instance, be rewarded with complete success.

In the preceding remarks on the composition of the Cornish rocks, it has been seen that there are, here and there, certain distinct and characteristic rocks: each of these, by gradual transitions through a series of layers or beds (which are sometimes compact, sometimes schistose), passes on either hand into those adjoining. These series may therefore be regarded as constituting genera, of which the central or characteristic varieties, commonly massive, and oftentimes crystalline rocks, are the types. If this view of the subject be correct, the primary rocks do not occur in a state of confusion, but are arranged side by side, according to their affinities, after the manner of a well-regulated museum.

To return to the description of the rocks of the porphyritic series: the hornblende rocks are, in a great measure, composed of compact and schistose greenstones, which repeatedly pass into each other, so that, in traversing them from the granite, they appear to alternate; this, however, does not take place to any great extent in the length of their beds, for sometimes the massive rocks are insulated in the body of the slate, and *vice versâ*. On approaching towards the granite, the greenstone is generally found to be harder, and becomes more and more siliceous, with quartz veins, which sometimes project on the side of the hills in blocks three or four feet in breadth: its hornblende gradually loses its characters, until at length it cannot be recognised as such, having passed into shorl, and thus the transition is effected into proteolite, the genus last described.

In like manner, proceeding over the greenstone in a contrary direction, towards the shores of Mount's Bay, the accessary mineral, hornblende, becomes gradually changed into actynolite, as is evident in those rocks which have a compact and crystalline structure. This genus is not of very common occurrence, and may therefore be noticed a little more in detail.

The most abundant species of actynolite-rock is hard and compact, known provincially by the names of *blue-stone* or *blue elvan.* This variety is accompanied by, and gradually passes into a blue slate, which is fissile in various degrees, and may also be easily separated into small rhomboidal pieces. The massive kind occurs in elevated ridges on the coast, and is very durable, whilst the slate is decayed to a considerable depth, still retaining its form, but progressively diminishing in tenacity from the perfect rock to the surface, where it is sometimes nearly as soft as clay: the blue colour of the slate has disappeared in the decomposed rock, which is ash-white, with ochreous stains, or of an uniform pale fawn colour; this property readily distinguishes it from slaty greenstone, with which it is nearly allied. Some of the compact kinds of this genus are very beautiful, having a light violet-coloured basis, which is variegated with stripes, and marbled markings of the dark blue species. The violet colour appears to be occasioned by the intimate union of axinite with the compact felspar basis of this rock; for axinite, in crystals, is often present, in the state of patches and small veins, traversing the rock after the manner of calcareous spar in limestone. At first sight, these rocks appear to be well calculated for ornamental purposes, but unfortunately they are traversed by numerous seams or joints, which become discoloured by exposure to the air, in consequence of the decomposition of iron pyrites. This mineral not only coats the joints of this rock, but is also sometimes disseminated throughout its substance in small amygdaloidal granules.

Each of the preceding schistose rocks, but more particularly the greenstone, gradually passes into thick lamellar slates, which exhibit various shades of blue and green, are soft, and abound in metalliferous veins, particularly of copper, the matrix of which is composed of quartz and dark green crystalline chlorite: they also contain layers or beds, which are compact and earthy, differing only from the slate in wanting the fissile structure.

Thus we find, that the rocks of the schistose group immediately surrounding the granite of Cornwall, may be referred to five distinct genera, viz. cornubianite, proteolite, greenstone, actynolite-rock, and chlorite-rock. To these it is proposed to subjoin a description of the magnesian rocks, the true position of which has perhaps not been decidedly ascertained, though it appears in Cornwall to be in the lowest part of the calcareous group, the upper part of which contains organic remains, and therefore it may possibly belong to the intermediate or transition class.

The magnesian rocks of this county may be divided into three genera: diallage-rock or euphotide, serpentine, and talc-schist; the last is generally received as a distinct rock, and, indeed, in other countries, it is extended over large tracts, with different associations; otherwise it might in Cornwall be regarded merely as a schistose species of serpentine.

The euphotide consists of felspar and diallage, both of which are very crystalline, and are generally very distinct, in the form of various sized crystals aggregated together, and mutually penetrating each other, after the manner of granite: its felspar does not appear to be identical with that of granite, which may be owing to the presence of magnesia, just as diallage differs from hornblende in containing a large proportion of this earth.

The constituents of euphotide, in some places, gradually become so small, that the rock is at length perfectly homogeneous; and where this is interlaminated with small scales of shining diallage, the rock acquires a schistose structure. This schistose euphotide has been commonly called hornblende slate; but it is so different from all the varieties of the latter, and has such a characteristic appearance, that it ought to be distinguished. It appears, sometimes, to be imbedded both in the euphotide and in the serpentine; and the latter rock, even in some instances, seems to be subordinate to the schist. The fact is, that the schist often forms the connecting link by which euphotide and serpentine graduate into each other; and though these rocks alternate on a given line, like the massive and schistose greenstones, yet they do not preserve a continuous course for any considerable distance; but mutually *abut* against, or are dovetailed into, each other; sometimes the one, and sometimes the other prevailing.

The serpentine of Cornwall is proved to be a compound of diallage and felspar; or perhaps, rather, of compact felspar, by its frequent transitions into euphotide. This rock exhibits a great many varieties; some of which are hard, whilst others are so soft as to yield to the nail. This difference appears to depend on the felspar base, which undergoes several modifications, between a crystalline, compact, and granular state, as seen in the precious, common, steatitic, and ollareous serpentines; in the same manner as the rocks of the porphyritic group assume various aspects, according to the composition of the compact felspar base; with this difference, however, that in these, the proportion of the silica modifies the compound, whereas, in the serpentine, the changes are attributable to the relative quantity of magnesia. The accessary mineral, diallage, also, imparts characters to the serpentine, according as it is intimately combined with the base, or is disposed in distinct forms. And, lastly, both of the component minerals, in all their modifications, traverse the serpentine in irregular strings, veins, and layers.

The talc-schist of Cornwall is not a compound of quartz and talc, as described in systems of geology, but of the same substance as forms the basis of the serpentine, intimately blended and laminated with talc; which mineral may be seen in distinct scales, in the quartz-veins and nodules which occur in this slate. It appears to be produced by the transition of the diallage into talc, in the same manner as hornblende passes into mica. It is worthy of remark, that the ollareous serpentine and talc-schist of Pollaphant, is accompanied by a bed of crystalline limestone; which is glossy and variegated by the intermixture of talc, and abounds in tabular spar and hornstone. This single instance is curious, as we find this association extensively developed in other countries.

In the foregoing enumeration of the Cornish primary strata, it may have been observed, that no mention has been made of the quartz-rock of Macculloch. This omission has been intentional, because nearly all the varieties of this rock do occur in Cornwall, and some of them occupy extended tracts, the boundaries of which are distinctly marked by barren downs: but the quartz is generally combined with the component minerals, or the substance itself of the adjoining slate; so that it appears to be a more natural arrangement, to consider these rocks as quartzose varieties of the slates into which they graduate.

It has already been stated, that the rocks of the schistose group are composed of compact felspar, united in various proportions with mica, shorl, hornblende, or some other accessary mineral; and that some species of these rocks are produced by the relative quantity of the component parts of the compact felspar base: thus, when silica predominates, the species becomes quartzose; and if it prevails, to the exclusion of all other substances, then it gives rise to masses, layers, or veins of quartz, which may be regarded as subordinate to the rock in which it occurs. This mode of classification appears to be more simple, and more in accordance with nature, when the quartz is blended with the substance of the adjacent strata; but when the quartz is pure, or combined with crystalline minerals, then it becomes a true quartz-rock; often graduating into hyalomicte, pegmatite, and analogous rocks, and must then be regarded as the equivalents of those granitic beds which are interstratified with the primary schistose rocks.

The same genus does not always contain a quartzose species of the same extent in every locality; this, like all the circumstances relating to the primary rocks, cannot as yet be reduced to any fixed laws: but it may be remarked, that the quartzose species very often form the connecting link, through which two adjoining genera pass into each other.

And it may also be here observed, that these quartzose rocks very often assume a brecciated or fragmentary appearance, evidently arising from some portions of the quartz being free from the colouring or slaty matter with which the greater part is intimately combined. The variegated and agate-like figures which these rocks assume, cannot be easily described; sometimes the pure, and sometimes the coloured quartz, predominates; and not unfrequently the latter resembles fragments of slate, the nearest sides of which, though sometimes many inches asunder, so correspond, as if they had been at one time united: but a careful scrutiny of this rock will convince every one, that this fragmentary appearance is only a curious coincidence; for if one part of it seems to support such an opinion, a thousand others will show that the rock could not have been formed by the aggregation or cementation of fragments. These curious fragmentary appearances are not peculiar to Cornwall: we shall, therefore, have occasion to revert to this subject, when treating of the structure of the primary rocks.

In order to complete the sketch of the schistose group of Cornwall, it remains to state, that granitic rocks often occur therein as large beds or dykes, called by the miners *elvan-*

courses. These rocks might have been treated of in a distinct chapter, or in connection with granite, but the plan here adopted is preferred, in order to present a faithful description, as free as possible from theoretical opinions concerning their nature.

By the term granitic rocks is understood such compounds as have already been described as forming portions of the central masses of granite. They seldom resemble true granite, but exhibit most of the species of shorl-rock, protogine, eurite, and felsparite, more particularly of those kinds which are porphyritic. These granitic rocks are most abundant in the vicinity of the granite; and very commonly, though not invariably, are found to underlie towards the main mass of granite at very considerable angles, averaging about 70° or 75°: that is, their dip generally differs from the inclination of the laminæ of the schistose rocks, which usually slope from the granite. The direction of these granitic rocks is, in general, from N.E. to S.W.; corresponding, in this respect, with the greater portion of the slates, and with the principal metalliferous veins: and like these, also, their course is not in an undeviating straight line, but is variously curved; and this character is also detected in their underlie. The great *elvans* of Polgooth mine may be referred to, as affording illustrations of this circumstance.

Concerning the kinds of slate, with which these granitic *courses* are connected, and the relations which they respectively bear to each other, it will be necessary to adduce some examples in detail; for this important subject will furnish some leading arguments in the subsequent examination of the prevailing theory.

The varieties of felsparite, described as one of the Cornish granitic rocks, are more frequently met with amongst those slates which have a similar hard compact felspar basis, as cornubianite, actynolite rock, and some of the species of greenstone. Examples of this association may be seen in Dolcoath, and other mines situated near the junction of the granite and the slate; but it is much better exhibited on the shores of Mount's Bay, where several beds of felsparite traverse compact and schistose species of cornubianite and actynolite rock, on the beach below high-water mark. One of these, near Penzance, is particularly deserving of attention; as a considerable portion of it is exposed to view, and is easily accessible. Immediately at the back of the pier, it may be seen stretching N. E. and S. W., and inclining at a great angle northward. It is a porphyritic felsparite (felspar porphyry), the imbedded crystals being small and white: these gradually disappear towards the sides of the bed, till at last this rock is a plain compact felsparite, very hard, apparently in consequence of an excess of silica in its composition; and in this part, veins of quartz are frequent, as is also the case in the adjoining stratum of compact actynolite-rock, at the point of their junction, where these rocks can only be distinguished from each other by the blue colour of the latter. This granitic bed is lost eastward, under the sea, and westward, under houses and the little neck of land which runs towards the battery; but on the other side of this small promontory, it again makes its appearance, and may be examined for nearly a thousand feet in length. It first emerges from under the sand-bank near the *chimney rock*, a prominent part of this bed; the highest part of which consists of a single prismatic block. The ground plan (*fig*. 1.) will serve to illustrate its position, and its mode of connection with the adjoining rock.

The part figured is situated between the chimney rock and the eastern extremity next the sand-bank, and is about two hundred feet in length: in some points the line of junction between the elvan and slate bears N. E. by E., or even N. E., as at the back of the pier; the general direction of the whole course, however, is E. by N. and W. by S., and the occasional departures from this are apparent in the plan. On the southern side the junction may be traced nearly two hundred feet farther; on the northern side, with little interruption,

Fig. 1.

Elvan Course, near Penzance.
(Ground Plan.)

for seven hundred feet: and although the course is very irregular in the part selected, the remainder of it, on the side exposed, exhibits a line very slightly undulated. As regards the dip of this elvan there seems to be a difference of opinion, Mr. Hawkins having stated that it underlies, in the Wherry mine, towards the S. W. one foot and a half in a fathom *, whilst Mr. Carne says that it dips north.† The appearance of the dip is very various: — at A, it is S. by E. at 45°; at B, N. W. at 70°; at C, it underlies the slate towards the S. E. very gently, and in a curved line, which, at a distance of ten feet, attains rather a higher level; at D, it is nearly perpendicular; on the northern side, at E, F, and G, the dip is uniformly to the N. W. at angles fluctuating between 60° and 70°. Now the more extended surfaces of the large concretions, in the middle of the course, generally dip at low angles to the southward, either E. or W. of this point, according to the curvature of the elvan; whilst the lesser surfaces decline in an opposite direction at elevated angles; and we therefore consider these to be the true bearings: the latter

* Geol. Trans. of Cornwall, vol. i. p. 140. † Idem, vol. ii. p. 82.

accords with the dip observed in the mine, and we consider the northern surface underlying the slate to be the termination of the elvan in width, for what is only seen here in part probably entirely obtains at both extremities, since they are lost under the schistose rocks; and we also think that some of the irregularities in the breadth of the elvan may be traced to the persistence or abrasion of the slate, more particularly the latter, as at A and C. The elvan is traversed by lines or joints, which cross it in the direction of S. by E. and N. by W.: these lines are very close together at G, and there the porphyry is much stained with oxide of iron, and is in a decomposing state; and the rock adjoining is similarly circumstanced. Where the elvan is a well characterised porphyry, the lines are farther apart, — that is, the elvan is composed of larger concretions. But the most important circumstance concerning these lines is, that they, in innumerable places, continue their course uninterruptedly into the slate, as may be well seen even at A and F, where the elvan is seventy-five and ninety feet in width. The same observation equally applies to the longitudinal joints, where they meet with the protruding slate. Lastly, it may be noticed, that at H there are several bunches and elongated portions of rock perfectly resembling the slate at its junction with the porphyry; and that at fifty feet north of E, the laminæ of the slate are very flat and undulating, sometimes rather inclining S., but oftener to the N. Beds of eurite are of frequent occurrence in the Cornish rocks, which it has been proposed to call proteolite; and in this case also we find a similar correspondence in the nature of their respective bases, both consisting of a soft and fine granular compact felspar.

Several beds of eurite occur between Camelford and Bodmin. At Tremagenna, it is a white rock, composed of compact felspar, in which are imbedded limpid grains of quartz, and scales of mica; it is also in some parts stained with rust coloured spots, produced by the decomposition of some adventitious mineral, probably of hornblende; and small irregular crystals of felspar may be observed here and there, but they are of rare occurrence: its junction with the slate is not exposed.

At Kernick, about three miles from Bodmin, there are several beds of granitic rocks: the mica is in larger scales than in the last, and small portions of hornblende are distinctly developed; and here also their junction with the slate on either side is concealed, so that their size and bearings cannot be ascertained.

About a mile and a half from Bodmin, on the road to Truro, an interesting kind of eurite occurs, which we have termed porcelainous eurite, as indicating its nature. It is of a pale greenish yellow colour, rather uniform and compact, but containing grains of limpid quartz: it decomposes to a considerable extent, and then resembles *china-clay*, which has been already described as a disintegrated protogine, a rock distinguished from granite by containing talc instead of mica, and which abounds in the mass of granite about three miles off. If this bed of porcelainous eurite were well exposed, its constituent minerals would probably be distinctly exhibited, as is generally the case in the middle of these *elvan-courses*, where the rock becomes porphyritic and even granitic.

Granular and compact shorl rocks also occur in this part of Cornwall imbedded in proteolite, and although at first sight these rocks appear to have a very dissimilar composition, yet a careful examination will show that they are nearly related. The proteolite is frequently coloured by or even intermixed with shorl, in various states; and when the compact felspar basis becomes siliceous, the shorl is present in greater abundance, till at last it graduates into compact shorl-rock, and the constituents becoming distinctly crystallised, the granular shorl-rock is produced. The celebrated Roach rock is composed of the last-mentioned variety: it rises out of the slate in the form of an immense tor, about a mile distant from the granite.

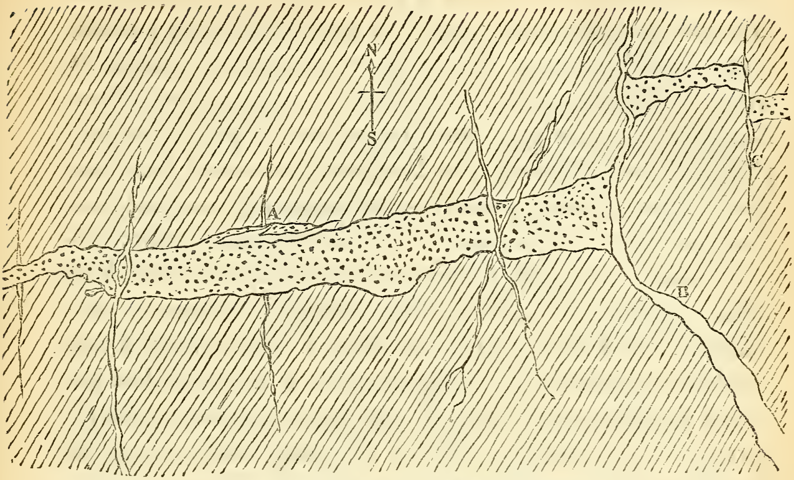
The granitic elvans (species of eurite) are very abundant between St. Agnes and Cligga Point, on the north coast, where they may be seen running in regular beds, alternating with the schistose rocks into which they gradually pass: some parts of these elvans are very shorlaceous and quartzose; and being on this account more durable than the felspathic kinds and the slate, they project on the shores in very abrupt ridges.

On the shore at Swan-pool, near Falmouth, there is a large elvan-course, the upper part of which in the cliff is extensively decomposed into a state of clay: its course on the shore may be traced for several fathoms in length; but what is more particularly worthy of remark is, that near low-water mark it abruptly terminates, but immediately adjoining it is seen running in a parallel direction at a distance of about twenty feet from its original course, which is exactly the width of this *elvan*. This is an excellent illustration of what the miners call a *heave*, and is interesting, as this phenomenon is not of such frequent occurrence as in the case of veins: in this instance the *elvan* has the appearance of having been intersected by a thin course of clay, or *flukan*, which, however, gradually tapers or dies away on the land side. At Mousehole, in Mount's Bay, a very large vein, or rather a course* of felspar porphyry, exhibits *heaves* by veins of quartz: the course is visible, at low water, for more than a hundred and fifty feet in length, and is sufficiently important to demand a particular description, which may be rendered more intelligible by the sketch. (*fig.* 2.)

The bearing of this course is a little S. of W. and N. of E., on an irregularly undulating line, dipping towards the N. at

* A large vein of a similar nature, at Cape Cornwall, ought to be considered as an elvan-course, according to Mr. Carne; but it matters not in which light these elongated granitic masses are viewed, because no line of distinction can be drawn between them. It is worthy of remark, however, that elvan-courses generally run parallel with the strike of the laminæ of the slates; whereas at both these places they cross them diagonally.

Fig. 2.



Felspar Porphyry, at Mousehole, Cornwall.
(Ground Plan.)

a very gentle angle. The porphyritic crystals of felspar are sometimes large and distinctly defined, but more commonly they have the usual imperfect forms of such crystals: they are not confined to the central part of the course, but often abound close to the junction; and in many cases it is difficult to say whether the slate or the compact felspar is the basis of this rock: this is particularly the case when the seams or open joints do not correspond with the line of junction, but cut off a portion of the slate, as happens at every step, so that both rocks compose the same individual mass or concretion, and cannot be separated from each other. At A the course divides into strings, so as to envelop portions of the slate which, together with the elvan, are mixed in irregular elongated portions, variously disposed: in several places portions of rock are imbedded in the elvan, which perfectly resemble the hard compact slate immediately adjacent to this course. Some of the quartz-veins abut against the elvan, others traverse it without any alteration; but the vein B produces a heave of twelve feet towards the north. On the western side, the elvan is ten feet wide, gradually enlarging from eight;

on the eastern side, it is only six, diminishing in its course to four and even three feet, when it is again heaved, by a small, quartz-vein C, towards the south, to a distance equal to its width. The vein B, in contact with the western elvan, is two feet wide; in some parts purely quartzose, in others porphyritic, and even blended with irregular portions of slate, the whole mass at many points passing gradually from one rock into the other It continues of the same nature and of the same thickness towards the eastern portion of the course; but, before reaching it, dwindles into strings, and forms a considerable curvature: passing the elvan a second time, it also involves porphyry in its composition for a few feet, then becomes quartzose and schistose, and runs a curved course for seventy feet, having a variable thickness, and sending off branches, and then dies away in strings. In its southern course, however, it assumes a great contortion, and at the same time becomes a hard compact variety of slate, in which state it disappears under the sea.

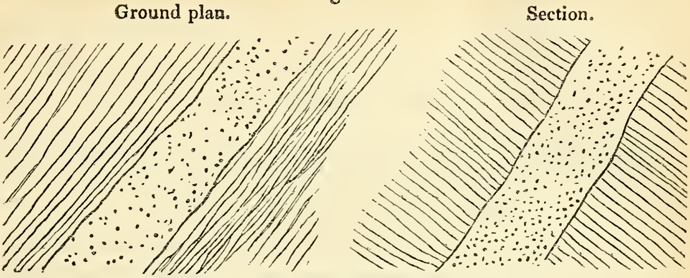
The courses or beds of granitic rocks, in the slates, sometimes exceed three hundred feet in breadth, and at other times they dwindle to such a small size, as to be called granite veins. These courses are subject to curvatures, in common with the containing slate, as has been already noticed; and they often send out branches or veins during their progress, as figured by Professor Buckland in the elvans of St. Agnes.* They sometimes terminate abruptly, as at Mousehole and Cape Cornwall, or, as in the northern end of the elvan at the latter place, gradually disappear in several small veins.† Lastly, near the granite or elvan-courses, these granitic rocks often occur in bunches or masses of various dimensions.

The direction of these courses is generally parallel with the strata, but the dip being very commonly towards the granite at a very considerable angle, varying from 45° to 75°, these granitic rocks cross the laminæ of the slates, as in the diagrams. (*fig.* 3.)

* Geol. Trans., vol. iv.

† See figs. 13. 16.

Fig. 3.



Pengersic Cove, Mount's Bay, Cornwall.

From the examples which have been adduced, we derive the important fact that the insulated beds or courses of granitic rocks always partake of the nature of the containing slate, which is not surprising, since it has been shown in this and the second chapter that both kinds of rocks have respectively the same bases.

Let us now turn our attention to the schistose groups of other countries; referring those, who are desirous of obtaining more minute details concerning the varieties and localities of the Cornish crystalline slates, to the fourth volume of the Geological Transactions of Cornwall.

CHAPTER V.

DESCRIPTION OF THE SCHISTOSE ROCKS ASSOCIATED WITH GRANITE IN VARIOUS COUNTRIES.

Mica-slate and clay-slate of the eastern part of Ireland. — Their alternations with quartz-rock and hornblende-rock, — their associations with granite. — The composition of this granite, and its modes of arrangement. — The gneiss formation of the Western Isles of Scotland. — Its beds of mica-slate, greenstone, compact felspar, clay-slate, talc-schist, serpentine, limestone, and quartz-rock. — The nature of their connection with each other and with the gneiss.— Abounds in bunches and veins of granite. — Description of the primary schistose rocks of Norway, — gneiss, mica-slate, clay-slate, — with their subordinate beds. — They contain immense beds of granite, and are interstratified with smaller ones. — The primary schistose group of Saxony, — gneiss, mica-slate, clay-slate, and shorl-schist. — The talcose formations. — Of the Alps, — including talcose granite or protogine, talc-schist, serpentine, and other magnesian rocks. — Of the island of Corsica, composed of granite, eurite, protogine, hornblende-rock, euphotide, talc-schist, serpentine, and analogous rocks.

In attempting to show that the primary or crystalline schists of different countries are the equivalents of those of Cornwall, it is not intended to assert that they are all of the same nature, and referrible to precisely the same geological epoch: on the contrary, it is wished, for the present, to avoid all conjectures concerning the nature of their origin, and only to express that these slates do, as in Cornwall, bear a certain relation to the granite with which they are associated; and consequently all slates, both foreign and Cornish, which have the same relative connection and position with the granite, may be regarded as parallel or equivalent rocks.

These equivalent schists are commonly of a very different nature, which might have been expected *à priori;* for even in Cornwall the suites of slates vary when connected with different masses of granite; still, however, although their composition is not identical, they undergo analogous mutations, resulting from the proportions of the constituent parts, and the manner in which these are united. Thus it has been shown that one insulated patch of Cornish granite is very felspathic and abounding in porphyry; another, shorlaceous, and containing numerous beds of protogine (china-stone); and a third, more micaceous than ordinary, and intersected by layers of eurite; and in each of these cases we have seen that the series of adjacent schists vary accordingly, and yet each series may be considered as the equivalent of the other.

Now let us proceed to examine the nature of the crystalline slates of other countries, and to enquire whether they bear the same relations to the accompanying granite, as obtains in Cornwall; or whether these rocks, in the latter case, are exceptions to the general rule, and have a peculiar arrangement.

In Ireland it has already been stated that the extensive mass of granite occurring in the eastern district presents a difference of composition in its northern and southern portions: in the former, it consists of the ordinary ingredients, being often quartzose, but exhibiting little variation of mineral character; whilst in the latter, quartz is not so abundant, and the felspar and mica are sometimes intimately incorporated, in some varieties resembling homogeneous trap, and in others verging towards clay-slate; and, in like manner, the adjacent schist is principally mica-slate in the north, and clay-slate in the south.

"This mica-slate," says Mr. Weaver, "wherever it occurs, is in direct contact wlth the granite. It consists of alternate layers of quartz and mica, from one line to two and three inches thick, and some layers of quartz extend even to two feet in thickness, while the surface of the intervening mica is almost invariably studded with cruciform and stelliform aggregations of hollow spar."* — "The mica-slate which occupies the lower part of Glenmacanass, on the western side, contains a bed of talc-slate, of uncertain thickness, both rocks dipping 25° towards the south-east. The talc-slate is of a greenish

* Geol. Trans., vol. v. p. 140.

grey colour, and interlaced fibrous texture, yet disposed in laminæ, forming a slate. It is soft, yet tenacious, works easily under the chisel, and hardens in the fire: it is quarried and wrought for various economical purposes."*

"Hornblende, in crystals disseminated through this mica-slate, is by no means uncommon; and sometimes this mineral becomes so intimately mixed with the slate as to constitute a compact tenacious compound; as, for example, in Aghole mountain. Beds of common hornblende probably occur also occasionally in the mica-slate, as detached blocks of that rock are sometimes to be seen; for instance, in the northern part of Carrigacrow, and in the lower part of Balreagh glen, towards Glencree river."†—"Brisselstown Hill consists of mica-slate, fine granular greenstone, greenstone-slate, and greenstone porphyry. Mica-slate appears on the eastern side of Brisselstown, beneath which is seen the granite base; but the southern side and summit are composed of the trap rocks just mentioned, principally the two first, which form a great bed in the mica-slate. This slate in the western part is porphyritic, containing numerous crystals of felspar, and it passes into greenstone porphyry by an intimate mixture of hornblende. This gradation from mica to hornblende is frequently observable in these rocks."‡—"On the southern side of Comaderry mountain are masses of trap rock: the higher part consists mostly of common hornblende rock, which varies in colour from green to black, and approaches even to the nature of massive mica. About the middle of the declivity, it is intermixed with felspar, mostly compact, and greyish white, the two substances constituting a coarse-grained rock; at times the felspar greatly predominates, containing hornblende and mica disseminated in its substance. Lower down the hill, the rock consists of a compact felspar base, with prismatic crystals of hornblende interlaced, and shooting through the felspar in every direction."§

* Geol. Trans., vol. v. p. 146. † Idem, p. 154. ‡ Idem, p. 161.
§ Idem, p. 147.

This mica-slate is in most places traversed by layers or beds of quartz rock, of various forms and dimensions; and, in addition to the minerals already mentioned, it incidentally contains andalusite, garnet, and sphene.*

On the southern part of this primary range, as already stated, the granite is not bounded by mica-slate, but by clay-slate, which is described by the same author as being yellowish, greenish, or purplish in colour; smooth, glossy, fissile, and free from admixture: but in general it is so blended with the rocks with which it is associated, that its true nature can only be understood after considering all its various relations. These rocks are clay-slate, conglomerate, greywacké, greywacké-slate, quartz rock, greenstone, and greenstone porphyry.

"The clay-slate conglomerate consists of angular fragments of clay-slate, some nearly as large as the head, with smaller fragments of quartz, imbedded in and cemented by clay-slate."

"The greywacké is composed of small rounded and angular grains of quartz, numerous minute scales of white mica, small fragments of clay-slate, and sometimes portions of felspar cemented by clay-slate. The greywacké-slate is a similar rock, with a slaty structure; and it is the predominating rock."†

"The quartz rock is generally white or yellowish-white, but is sometimes more or less stained with yellow, red, and brown. In its structure, it varies from the perfectly compact splintery to the close-grained granular; sometimes containing small, well-defined, rounded grains of quartz, which are frequently of a different colour from that of the base; but it contains very rarely rounded and angular grains of felspar, and a few scattered minute scales of mica. Such is the character of the pure quartz-rock: but it is not only interstratified with clay-slate on the large, but on the small scale; and it is in these alternations that reciprocal incorporation takes place, presenting rocks in some instances of a homogeneous character, and in others of a distinctly compounded structure.

* Geol. Trans., vol. v. p. 154.

† Idem, p. 165. et seq.

In the former modification, quartz-rock becomes tinged throughout its mass of a yellowish, greenish, or purplish colour, by an infusion of the matter of clay-slate, and passes occasionally even into hornstone and flinty slate. As the proportion of clay-slate increases, the compound becomes entitled to the name of quartzy clay-slate; and at last it passes into pure clay-slate, both compact and fissile. In the beds, in which quartz predominates, scales of mica sometimes occur, and are disposed without order through their mass. In the slaty beds, however, they appear frequently arranged in the direction of the laminæ, silvering over the planes of separation. Quartz-rock, impregnated with the matter of clay-slate, frequently envelopes grains of quartz, scales of mica, sometimes, also, grains of felspar, and rarely minute portions of clay-slate; thus constituting a firm compact variety of greywacké. When clay-slate matter predominates, it passes into greywacké-slate. All these varieties of quartz-rock are more or less traversed by small contemporaneous veins and strings of pure white quartz, which in their range frequently follow the line of the dip."*

"The greenstone, as at Dunganstown Hill, is near the summit more crystalline than in other parts, composed of distinct crystals of felspar and hornblende; but in general hornblende appears only in spots, or as colouring the felspar mass, which is partly compact and partly foliated, and in which are disseminated minute crystals of felspar. The grain varies from fine granular to compact; and the common character of the rock in the latter state is that of a greyish green base with an uneven fracture, which contains disseminated minute crystals of glassy felspar. In the north-eastern part of this hill the greenstone approaches more to the nature of an ash-grey compact felspar, partly vesicular, the vesicles being mostly empty, or slightly coated with iron ochre, derived from the decomposition of iron pyrites, which is present in these trap rocks."†

* Geol. Trans., vol. v. p. 185. † Idem, p. 170.

Mr. Weaver also gives an excellent account of the association of granite with the slates; from which we find that entirely detached portions of the former occur in the latter rocks, after the same manner as the granite in the slate of Cornwall. Thus, "in following the northern ravine from Glenismaule upwards, we meet with granite alone for about three fourths of the ascent, when mica-slate appears in contact with and resting upon the granite; the strata standing nearly on their edges, ranging N. E. and S. W., and dipping 75° to the N. W. In this spot the granite exhibits some disposition towards the structure of gneiss, but to a small extent only. A little higher up the mica-slate is better exposed, and contains thin layers of quartz, sometimes pure, sometimes mixed in part with felspar. Considerably higher up a bed of small-grained granite occurs in the mica-slate, about six inches wide, the range and dip being the same as the slate; and within a few inches of this bed of granite is another of the same width, but of short continuance, terminating abruptly at the S. W. and edging out on the N. E., being thus completely enclosed in the mica-slate, the laminæ of which follow the line of the granitic bed, which is about fifteen feet in length. We next come to a third bed of granite, but of less dimensions, or rather to a vein, terminating also abruptly in the mica-slate; and upon its sides we perceive portions of the latter rock impressing and indenting the former in a very singular manner. There are also layers and veins of quartz, a few inches thick, either pure, or mixed with felspar, terminating likewise abruptly in the mica-slate."

"Higher up this ravine is a short compressed elliptical mass of granite, enclosed between the laminæ of the mica-slate; and beyond this is the horizontal section of what appears to be a granite vein nearly enveloping a portion of mica-slate. The parallelism of the laminæ of the mica-slate does not appear to be affected by this disposition of the granite." *

* Geol. Trans., vol. v. pp. 155, 156.

The granite and the mica-slate not only occur in each other in the state of irregular portions, but in numerous instances were found, by Mr. Weaver, to alternate in large beds, the position of which is so distinct, that their nature cannot admit of a doubt, as in the case of Polgooth mine, in Cornwall. This phenomenon is so important in the history of primary rocks that it is desirable to quote some examples in detail.

" In Glenmalur, nearly one half of Lugduff, which borders the glen on its north side, is composed of these alternations, the study of which has been greatly facilitated both by nature and art; the northern face of Glenmalur being furrowed by several ravines, and the lead mine of Ballinafinchogue being situated in this quarter. Ascending the ravine, the water of which turns the wheel of the upper smelting-house, we find the following succession of beds: —

1. Granite, at bottom, of uncertain thickness, upon which rests	
2. Mica-slate, including many layers of granite, which alternate with the mica-slate, forming a body - - -	24 feet thick.
3. Granite - - -	12
4. Mica-slate and granite, forming an indistinct intermixture - - -	36
N. B. The preceding beds include also frequent thin layers of quartz.	
5. Granite, the lower part of which is most curiously interwoven with contemporaneous veins of granite and quartz -	90
6. Mica-slate - - -	462
7. Repeated alternations of granite and mica-slate, forming a body - - -	132
8. Mica-slate - - -	372
9. Granite - - - -	9
10. Mica-slate - - -	120
11. Granite - - - -	30

N. B. The general character of the upper beds of granite is that of granular quartz, with much silvery mica, and very little felspar.

12. Mica-slate is traceable in the ravine up to the cattle pond, through an ascent of about - - - - 720 feet thick.

" Some of this mica-slate contains a vast quantity of grenatite, particularly the bed marked No. 8., generally in very small crystals, but sometimes in groups of large cruciform and stelliform crystals, well displayed in *alto relievo* on the rock by the wasted state of its surface." " The relations of the rocks at the lead mine are equally interesting to the geologist." " The whole of these alternations may be computed at one third of a mile in thickness, measuring at right angles with the dip." *

In the southern portion of this part of Ireland, granite alternates in the same manner with clay-slate. " At Croghan Kinshela," says Mr. Weaver, " granite supports clay-slate; and some thousand fathoms of trenches having been cut down to the solid rock in quest of auriferous veins, the mineral structure of this mountain has been fully disclosed. The western arm and brow of the mountain consist wholly of granite. The northern brow exhibits the following succession of rocks proceeding eastward, across the line of their direction :—

1. The fundamental granite. It is composed of yellowish or greyish-white felspar, grey vitreous quartz, and blackish-green mica: the felspar predominating, and the mica being in the smallest proportion. It is traversed by veins, consisting of white quartz with a greasy lustre; and greenish-grey clay-slate, containing cavities lined with quartz crystals.

* Geol. Trans., vol. v. p. 148. *et seq.*

2. Greenish grey clay-slate - - - 48 feet.
3. Granite, and some clay-slate - - 66
4. Greenish-grey clay-slate - - - 894
5. Granite - - - - 96
6. Clay-slate and granite in repeated alternations: the former sometimes containing large grains of translucent quartz, and occasionally, also, a few crystals of glassy felspar - - 192
7. Granite - - - - 960
8. Greenish-grey clay-slate - - - 90
9. Granite - - - - - 126
10. Clay-slate, greenstone, and greenstone-slate, in alternation - - - - 120
11. Ash-grey clay-slate, with some small beds of greenstone and greenstone-slate towards the latter part - - - - 666
12. Ash-grey clay-slate - - - 528
13. Greenstone; constituting the body of the hill at its junction with the northern arm.

" This greenstone, examined by the lens, is seen to consist of minute crystals of yellowish-grey felspar, intimately mixed with spots of black hornblende; its aspect to the naked eye, being greenish or bluish-grey, with a compact, small-grained, and uneven fracture. The compact greenstone, near the clay-slate, acquires a fissile texture."*

Again, " in the line of the Avonbeg, on the side of the mail-coach road, may be seen repeated alternations. The beds in the clay-slate, at first view, seem to be granular felspar; but a closer examination shows that they mostly consist of a fine-grained granite; the three constituents of which are, in some places, distinctly discernible. The alternation is as follows: —

1. Granite - - - 4 feet wide.
2. Clay-slate - - - 36

* Geol. Trans., vol. v. p. 172.

3. Granite, with a few thin layers of slate		18 feet wide.
4. Clay-slate	- - - -	18
5. Granite	- - - -	6

"About one quarter of a mile from the meeting of the two Avons, there is a fourth and a fifth bed of granite, similarly composed; each about nine feet thick, separated by clay-slate of thirty feet in thickness."

We cannot conclude this summary of Mr. Weaver's valuable observations on the primary rocks of the East of Ireland, without recommending to the student a careful perusal of the original.

Dr. M'Culloch, in his excellent work on the Western Islands of Scotland, has furnished us with copious details concerning the primary schistose rocks. We will, therefore, avail ourselves of this vast fund of information, to select such descriptions as our limits will admit of; more particularly concerning the gneiss, and the various rocks with which it is associated.

The mineral composition of the gneiss of these islands is the same as that of this rock on the mainland, viz. felspar, quartz, and mica; but the latter mineral is more frequently replaced by hornblende. The varieties of gneiss, as in the case of other primary rocks, depend not only on the proportion in which its respective minerals are united, but also on the mechanical manner in which these are arranged. Founded on the latter circumstance, the true and well-characterised gneiss may be divided into two kinds,—the granitic and schistose; both of which, however, will be found frequently to pass into each other by almost imperceptible gradations: this arrangement, therefore, is only one of convenience.

These kinds are of such frequent occurrence, that a single example of each must suffice. In South Uist*, the gneiss is almost uniformly of a granitic aspect; and its external forms

* Western Islands of Scotland, vol. i. p. 95.

are also so much like those of granite, as at first sight to mislead an observer: but a careful examination will always detect, somewhere, an indication of a foliated structure. This is particularly the case about Kilbride; but the gneiss resumes the more common foliated character, as it approaches the shores of Loch Boisdale. In Iona and Tirey, the gneiss generally contains hornblende, the mica being more rare: and although it is found even together with the hornblende, it is most generally observed in the vicinity of the granite veins by which the gneiss is traversed. In some places, the gneiss is perfectly foliated; but in others, it approaches so near to granite, that its nature can only be discovered by a favourable fracture. There is no regular progress from the granitic to the schistose beds, but they seem to be every where mixed without order. Indeed, the gneiss generally, in Tirey, does not exhibit any regularity of disposition, or even such an approach to it, as to show the probable course of the beds: or if, for a small space, any line of direction be traced, at the very next step the appearance of regularity vanishes.*

The beds of gneiss are generally disposed in the direction of N.E. and S.W., in conformity with the other primary stratified rocks in this part of Scotland, dipping towards the east at various angles. But it often happens, that the direction of these beds is very irregular, and accompanied by every possible variation of dip. Thus, in Rona there is on the eastern side a great sequence of straight beds, dipping uniformly towards the east; while on the western, they lie in a contrary direction; the two meeting in the middle of the island, like the roof of a house. In other places, the same beds will be found reversed; the eastern beds dipping to the west, and *vice versâ:* or they undergo changes still more intricate, displaying wavings and contortions. These irregularities, however, are more frequently limited to the granitic gneiss.†

Since mica is an ingredient in gneiss, it is not surprising

* Western Islands of Scotland, vol. i. pp. 45, 46. † Idem, vol. i. p. 213.

that it is sometimes predominant. In the island of Coll, it gives rise to distinct beds of mica-slate, alternating with the gneiss. This mineral is also, in the same place, so developed, as to form large concretions. The mica, in this state, is always black; in some cases crystallized, and in others, disposed in large plates without any definite form: and it is often so intimately mixed with hornblende, that it is difficult to distinguish one ingredient from the other.*

It has been already stated, that this gneiss is characterised by the presence of hornblende; which, with felspar and quartz, often constitutes the gneiss, to the entire exclusion of mica. The quartz, also, occasionally disappears; in which case, the rock puts on an appearance intermediate between gneiss and granite: again, by becoming of a finer grain, or by the exclusion of some of the felspar, it gradually passes into a simple hornblende-schist, or into that mixture of hornblende and felspar called primitive greenstone; and in some cases, into an unfoliated hornblende-rock. It is also not uncommon to find in this hornblendic gneiss larger or smaller laminæ, lumps, and even beds of hornblende-rock. These appearances are well displayed in Tirey†; and in Lewis, where they also occur, the gneiss exhibits an intermixture of a dark and pale colour, in pretty equal and parallel laminæ; the darker parts abounding in hornblende, the lighter in felspar.‡ But the most curious disposition of the hornblende is to be found in the gneiss of Coll, where nodules of hornblende-rock, of considerable size, are completely enveloped by concentric layers of gneiss.§

The felspar in the gneiss of the Western Islands is generally uniformly intermixed with the other ingredients; but sometimes it is distinctly developed, imparting to the rock an imperfect porphyritic character. This felspar is splendent, or nearly glassy; and the concretions, though highly crystalline within, have no external configuration: they are seldom

* Western Islands of Scotland, vol. i. p. 63.
† Idem, p. 46.
‡ Idem, p. 193.
§ Idem, p. 64.

less than a quarter of an inch in diameter, and attain to that of three inches. These concretions are often thickly disseminated, and disposed in a laminar direction, corresponding with the general structure of the rock; the laminæ of which, however, are sometimes bent and accommodated to the shape of the felspar.* These imbedded concretions of felspar are not always crystalline, but are found gradually passing into the common foliated and compact varieties of this mineral.

In the latter state, the felspar occurs often in the form of veins, laminæ, and even beds parallel with the strata of the gneiss: it exhibits various tints of yellow and green, and is often combined with other minerals; thus becoming, in some instances, porphyritic: of this nature is the porphyry vein traversing the gneiss, in the island of Iona.† The gneiss of these islands frequently passes, by the most imperceptible gradations, into a fine fissile slate: and this is always the case when the gneiss contains compact felspar.

The gneiss sometimes becomes talcose, and it is then associated with magnesian rocks. This occurrence is well displayed in the island of Scalpa; where, in consequence of extensive excavations for the lighthouse, a bed of serpentine has been exposed, traversing the promontory, and disposed in an irregular manner, like the gneiss in which it lies. The gneiss, in the vicinity of the serpentine, is in some parts almost an entire mass of compact felspar, mottled with red and white, and its laminar disposition being sometimes marked by alternations of these colours: it is occasionally interlaminated with clay-slate, and more rarely with talc; forming a talcaceous gneiss, which here marks the boundary of the serpentine. In other places, the transition between these rocks is effected by a serpentine, so full of hornblende, as to be scarcely distinguishable from a true hornblende-rock. Some parts of this rock are schistose; their colours being likewise disposed in a laminar manner, so as to present a dark greenish basis, striped, and in some directions speckled,

* Western Islands of Scotland, vol. i. p. 193. † Idem, p. 21.

with a paler tone of the same colour. These generally lie near the gneiss; the interior gradually assuming a more massive form, and displaying, at length, a fracture from which all appearance of a foliated tendency has vanished. Talc-slate is also occasionally found at the limit of the gneiss, mixed more or less with quartz of a very greasy aspect. In the interior of the latter rock, the bed of which, at its thickest part, may be about a hundred yards, a body of potstone is found; the harder serpentine passing into it by gentle degrees. This serpentine is of a dark green, and somewhat translucent on the edges, like wax: it contains veins of dark green, and of pure white steatite, sometimes fibrous, together with splendent veins of greenish asbestos.*

The gneiss of the Western Islands, like that of the mainland of Scotland, contains limestone. In Tirey, this calcareous rock occurs in several places. Not far from Balphetrish, it is of a reddish hue; varying from a high flesh-colour to nearly white, and from a muddy crimson to a dull purple. It is of a fine splintery fracture and smooth grain. It is an irregular mass or nodule, of about a hundred feet in diameter, and is surrounded on all sides with gneiss. It is not, therefore, a bed, as it is sometimes improperly so called, but a nodule; a form common to the greater number of limestones found in gneiss and in mica-slate. It is not capable of being raised in parallel-sided masses; yet, after exposure to weather, it splits into laminæ with great facility. It contains concretions of hornblende, but more commonly of augite; the green colour of which contrasts well with the red colour of the ground. The contact of this rock with the gneiss is well defined; and of all the component parts of the latter, quartz is most generally in union with the limestone; and is, probably, intimately combined throughout its mass, as indicated by the great hardness of this marble. Lumps of granite or gneiss are occasionally imbedded in this lime-

* Western Islands of Scotland, vol. i. p. 168.

stone.* At Gott Bay, in the same island, a bluish limestone alternates with the gneiss in a nearly vertical set of irregular beds, of no great extent; and both of these rocks are traversed by granite-veins. In the island of Iona, limestone also occurs; but, in this case, it is not associated with a true gneiss, but with a slate, intermediate, according to M'Culloch, between gneiss and clay-slate. It appears to be a schistose variety of compact felspar, which, in a massive state, occurs in this slate; and both of which are connected with and pass into gneiss; and it may, therefore, be considered as an integrant part of this series of primary slates. This limestone also exists as a large irregular nodule, of about thirty feet in breadth, and more than a hundred yards in length. The texture of this marble is compact, its fracture splintery, and its colour white, often with a slight greenish tinge. In many parts, it is fissile; more particularly where it approaches the schist, in which it lies: here also it becomes magnesian, and gradually passes into a steatitical calcareous schist, which contains leaves of translucent steatite; also dark-green foliated steatite, accompanied by yellowish-green and dark green noble serpentine. This limestone not only gradually passes into the adjacent schist, but both are contorted, and entangled together in a confused manner.† The masses of primary limestone are, however, much more extensively developed on the mainland; an interesting example of which, at Glen Tilt, will soon be considered more in detail.

In many parts of the gneiss of the Western Islands, the quartz so predominates, either in alternating laminæ with the other constituents, or in the state of a granular mixture, or even to the exclusion of the other minerals altogether, that it produces regular beds of quartz-rock of various extent. But the most interesting feature of this gneiss is its frequent intersection by granite-veins, which are so abundant, that they are rarely absent for any considerable space.

* Western Islands of Scotland, vol. i. p. 48. † Idem, pp. 17, 18.

In composition, the granite of these veins cannot sometimes be distinguished from ordinary granite; more generally, however, it possesses a distinct character, consisting chiefly in the larger size and more decided crystallization of its constituent parts; and occasionally, the mica and hornblende being absent, it gives rise to that peculiar variety called graphic granite. These veins are infinitely various in size, and in the number and intricacy of their ramifications. At times they intersect each other, so as to produce even a reticulation of the general surface, their intersections being sometimes attended with shiftings of the veins, while at other times, they cross each other without any disturbance. In some kinds of gneiss, they are so abundant as nearly to exclude the basis altogether, so that the mass presents little else than a congeries of veins. An instance of this occurs in the Flannan Isles, but the most remarkable one is to be seen on the mainland, between Loch Laxford and Cape Wrath, where the gneiss and hornblende-schist, in angular pieces, are entangled among the veins, resembling a variegated marble; and these fragment-like portions do not form a twentieth part of the whole mass, whilst one set of veins is intersected by a second and third, of different textures. The granite-veins are most abundant, and most intricately arranged, in the granitic gneiss; whilst, in the regular schistose variety, they are generally disposed in laminæ, which are parallel with the beds, and alternate therewith, as is well exhibited in the island of Coll. This parallelism sometimes continues for a considerable distance; at others, it is only for a short space, and the veins, quitting their even course, become either thicker or thinner, and cut through the laminæ. It is also worthy of remark, that lumps of granite, apparently independent of veins, are often imbedded in the gneiss: these differ much in size, and when they are large, they commonly give out branches or veins, which diverge in a very capricious manner, crossing and uniting with each other, so as to produce a most intricate reticulation. These granitic veins not only intersect the gneiss, but also the limestone, and other beds contained therein; and, in traversing the serpentine of Scalpa, already noticed, they consist of the usual mixture of felspar and quartz, with talc superadded, thus partaking of the composition of the magnesian rock through which they pass.

Such are the leading features of the primary schists of the Western Isles of Scotland; and to these might be added a description of the chlorite-schist, clay-slate, and quartz-rock, which compose the more southern islands; but, by so doing, the details would far surpass the limits of this work, in consequence of the complicated and undefined nature of these rocks, owing to the present imperfect state of geological nomenclature. Dr. M'Culloch has indeed given a copious and circumstantial account of these islands, and his work ought to be very carefully studied by all who are desirous of obtaining a knowledge of the primary rocks.

In the northern part of Europe the crystalline rocks appear to abound over very extensive tracts, and although the climate and the impracticable nature of the country oppose great obstacles to their minute investigation, yet they have been carefully examined by several distinguished geologists.

For the present, however, Von Buch's descriptions of the rocks of Norway and Lapland must suffice; and as far as the limits of this work will admit, it is proposed to give an outline of his observations, which bear on the subject now under consideration.

Von Buch observes that the Swedish and some other foreign mineralogists have described granite as of frequent occurrence; but that he has ascertained that this rock is a great rarity in Sweden, as well as in the whole of the north. This is in accordance with the experience of Haussmann, who has affirmed that granite, such as occurs in Saxony, Silesia, the Hartz, and in Lower Austria, was never seen by him in Sweden. The rock thus mistaken for granite is, says Von Buch, a clear and decided gneiss; it is distinctly slaty, and its mica lies in scales one above another, and never in single folia, as in granite: and it contains beds of hornblende, limestone, and ores.*

This gneiss, like the primary rocks already described, is constantly changing its appearance, according to the proportion and the nature of its constituent parts, which are commonly felspar, quartz, and mica.

Around Kongsvold the gneiss is fine, slaty, with detached folia of mica, which lie parallel to each other. This is near the mica slate; but, farther down, in the Straits of Drivstuen, rocks of a most beautiful gneiss are to be seen, containing large, and generally twin, crystals of white felspar, which shine forth in the midst of thick scaly mica. The felspar crystals are very much heaped together, sometimes the size of the hand: the mica is shining and easily separated: all the ingredients are distinct and determinate.†

In the straits of the Figa Valley, the gneiss appears in great rocks by the road-side, the mica of which is black and scaly, and the felspar distinct. It contains beds of a coal-black colour, which seem, in fact, to have been taken for coal, for they have evidently been worked; but they are entirely composed of pure, thick, scaly, and shining mica: this mineral, in isolated masses, is not unfrequent in the gneiss; but it is a singular circumstance to find it in whole beds.

This gneiss frequently contains hornblende, and even alternates with hornblende rocks. At Morstue, gneiss is the predominating rock, containing here and there subordinate beds of hornblende rocks: but, through the Mordskov to the eastern bank of the Miösen, the latter gradually increase in quantity, till the gneiss, with white felspar and a great deal of mica, only occurs as beds; and, at last, black hornblende and white felspar, in a fine granular mixture, entirely prevail. "This sort of alternation of beds," says Von Buch, "which gradually appear more and more frequently, is quite usual when one rock takes the place of another: thus, mica slate is

* Travels through Norway and Lapland, p. 21. † Idem, p. 102.

very frequent in the north, as a bed, in gneiss, before it preponderates over this rock; and in the same manner gneiss forms extensive beds in mica-slate, before the former becomes predominant." *

The gneiss in the hills of Cassness abounds in garnets: granular grey felspar and quartz lie between the mica, the scales of which are not continuous, but so close together that they form uninterrupted planes. Small granite-veins here frequently traverse the gneiss: the granite is composed of white coarse granular felspar, grey quartz, and a little mica. It is worthy of remark, that whenever granite occurs, the felspar immediately increases, and the mica diminishes or disappears. This gneiss is in immediate contact with mica-slate, which contains white crystalline marble. †

In the waterfall of Muonioniska the gneiss is *in situ*, and the stratification distinctly marked: it is not rich in mica, and the felspar is small, granular, and white. Following the course of the river, however, it becomes more micaceous, and contains granular limestone of a dark bluish grey colour. Near Kängis the white gneiss disappears, and is changed into red granite, the *Rapakivi* of the Finlanders: it is a coarse granular rock; its felspar is red, and in great abundance; its quartz bluish grey, in small quantity, and not always to be easily distinguished; its mica is black, in small single folia, and is exceeded in quantity by black hornblende. ‡ On the declivity of Pullingi, this granite gives place to white gneiss; but near its summit, the red granite again appears. This alternation continues over a large tract of country to Torneo, as is indeed also the case from this place to Christiana; but the granite is generally white, and the gneiss abounds in crystalline limestone. "It is singular," remarks Von Buch, "to observe the frequent changes of gneiss into granite. For several miles the granite appears to be predominant; then the gneiss as a bed occurs in the granite, and this happens more

* Travels through Norway and Lapland, p. 76.

† Idem, p. 200. ‡ Idem, p. 360.

frequently, until these rocks alternate in equal abundance and extent; but slaty undulating gneiss at last prevails every where." *

Thus we learn that, in these northern regions, the granite and gneiss are constantly passing into each other; so that it is often difficult to determine to which of these the rocks are to be referred; for the slaty structure, which is the grand distinction, is not always to be detected. For example: "The mountain of Luröe is composed of gneiss, and on the whole of the ascent the shining felspar is not concealed between the laminæ, as is often the case in these islands. The detached masses would lead one to suppose that the rock of this mountain is granite, but the mixture is too indefinite, and, even in these loose blocks, the slaty structure of the rock is betrayed by the flat position of the scales of mica." † "In the island of Grydöe, the gneiss is distinct and beautiful: the large cubical blocks, at the foot of the cliffs, render it evident that the slaty ingredients have not here their usual ascendancy; the mica is rare, and in small parallel stripes; the felspar is red and small granular, and the quartz in small quantity and not distinct." ‡

Such are the leading facts concerning the gneiss in the north of Europe. This rock is generally succeeded by mica-slate, with which it alternates, and into which it repeatedly passes, by a gradual change of its mineral characters, just as it does with granite.

In the rock of the island of Stegen, the felspar is so concealed, that traces of it are only here and there visible between the scales of mica; which, however, are not continuous, as is usually the case in the mica-slate, but appear as large scales lying close above one another. It contains garnets in great abundance, often as large as hazel nuts; and beds of granular quartz and hornblende, both with and without felspar. This rock constitutes the intermediate link

* Travels through Norway and Lapland, p. 396.
† Idem, p. 149. ‡ Idem, p. 165.

between gneiss and mica-slate; passing, on the one hand, into the former by an increase of felspar; and, on the other hand, into the latter by the disappearance of this mineral in a distinct form.

On the height of Stördalen, the undulations of the mica-slate may fairly be compared with the waves of a stormy sea; they are so large and long, and rise and fall in such a manner, that it becomes extremely difficult to discover, from these slates, the inclination of the strata. Besides, the surface of these curves is so wonderfully indented, that the slates appear to be fixed into each other like swallow-tails; and this structure prevails throughout the whole length of the mountain.*

At Bergen, the mica-slate first follows the great gneiss formation; then comes the gneiss of the islands, in which beds of mica-slate are very frequent; and this is again succeeded by mica-slate, of a nature which approximates to clay-slate.†

Around Forvig the mica-slate does not contain felspar, but envelops beds of white limestone. This continues to the foot of the mountain, Bevelstadsfieldt, where felspar makes its appearance in large shining crystals, which nearly displace all other ingredients; and the slaty texture disappears. By far the greater number of these crystals lie parallel to each other, dipping towards the east at 60°, exactly similar to the adjacent mica-slate. The mica between the felspar is black, and never continuous; and the quartz is not abundant. This granite is of great extent, not in a single bed, like the gneiss with the large crystals of felspar at Kongvold and Drivstuen; for, from the foot to the top of the mountain, a height of more than 1600 feet, its continuation is scarcely interrupted. In this granite, large crystals of tourmaline are not rare, surrounded by mica: there is no hornblende, but a few black beds, especially near the summit, consist of fine mica, interlaminated with a little felspar, and a few thick beds of quartz.‡

* Travels through Norway and Lapland, p. 117.

† Idem, p. 132. ‡ Idem, p. 137.

Porsangernäs is a very conspicuous object, and, when seen from Kielvig, appears to be covered with snow. It is, however, only white quartz in thick beds between layers of mica-slate. This quartz is so thinly stratified, that it separates into very large plates, several feet in length, and only a few inches in thickness, like marble tables. The mica-slate abounds in garnets, and in nodules which are harder than the basis; and are composed of a fine granular mixture of white talc, red garnet, and white felspar. These nodules not unfrequently impart a very singular appearance to the whole rock.*

The mica-slate of Leuvig contains neither felspar nor garnets, but several beds of granular dolomite; and above these beds, and even in the dolomite itself, are great layers of pure tremolite with green mica, like talc.† Von Buch gives several excellent details of the intimate connection and transition of mica-slate into magnesian rocks, which appears to be effected by the change of the mica into talc, and the pure limestones into dolomite. These excellent descriptions, however, are too long to be quoted in this work, and will scarcely bear abridgment.

The mica-slate also very frequently passes into clay-slate; that is, into a rock which is very fissile, and of a fine uniform texture: and this change is effected so gradually, that it is difficult to determine where the one begins and the other ends. We shall quote one example from Von Buch, which is also interesting in other points of view.

"To what formation does the rock belong which predominates between the Gundal and Drontheim? Are we to consider it as mica slate or as clay-slate? On the Steinberge, towards Drontheim, downwards, it appears at first sight completely to resemble clay-slate: the rocks are very fissile, and the laminæ are not shining, but have dark-coloured scales of mica scattered over their surface; and these betray the true nature of the rock; for such micaceous folia are not frequent

* Travels through Norway and Lapland, p. 287. † Idem, p. 205.

in primitive clay-slate. Small crystals of hornblende not unfrequently also appear, but no quartz, except in isolated and rare beds. Nearer the valley of the Nid, however, the mica appears continuous and shining, in the manner of mica-slate, but always fine and straight, slaty, and without quartz, which we should rather expect to be the case in clay-slate. At Küstad, about two miles from Drontheim, the rocks occur in other forms. The mica can no longer be mistaken: its folia surround a kernel, and form large balls of two and three feet in diameter. The kernel is extremely compact and hard, fine splintery or fine granular in the fracture, and of a bluish grey colour. It is probably a mixture of much compact felspar, a little quartz, and fine mica folia. The surrounding mica is also bluish-grey, glistening, and continuous, and every where covered with a multitude of beautiful pinchbeck-brown scales of mica. These balls lie close together, and whole rocks consist of them. We are frequently tempted to consider them as a conglomeration of large blocks; but the nature of the mica, and the position of this rock between other strata of mica-slate, distinctly prove that it cannot be separated from the mica-slate formation; this indistinctness of character and constant change in its ingredients show, however, that the mica-slate approaches very nearly the transition into clay-slate.*

The clay-slate, also, like mica-slate, often passes into magnesian rocks: first, it becomes very fissile, soft, and unctuous to the touch; and then it is found to contain beds of a talcy nature, resembling potstone, which is composed of fine granular talc mixed with quartz, and its properties vary according to the proportion of these minerals: sometimes it is very fine grained and semi-hard, with splintery fracture, and when talc prevails it is soft and sectile.†

The composition and the geological relations of the rocks of the island of Kielvig are very remarkable, and deserving

* Travels through Norway and Lapland, p. 106. † Idem, p. 91.

of accurate consideration, as they not only determine the constitution of the most northern part of Europe, but furnish us with information which can hardly be found either so full or so distinct in the interior of mountains.

The cliffs, and small islets on the shore, are not composed of gneiss; for the whole exterior of these rocks, their fine slaty structure, and the earthiness of their cross fracture, pronounce with distinctness that we are entering on clay-slate; but the shining surface of this rock resembles mica-slate: the scales of mica, however, although abundant, are only scattered on the continuous base of this slate. These strata contain beds of massive brown quartz, in which delicate fissures are frequently coated with chlorite, with occasional imbedded crystals of felspar. Large folia of talc, and small greenish-grey splintery cones, resembling serpentine, are not of uncommon occurrence.

Ascending Kielvigs-Eid we find *small-grained granite*, containing insulated folia of black mica and a great deal of hornblende: the line of separation of these rocks may be followed for a considerable length, and it may be clearly seen that the clay-slate is continued beneath the granite. This granite frequently changes itself into straight slaty gneiss, in which large and beautiful garnets often occur. In some places, however, this granite contains diallage and but little quartz; and by the former mineral gradually increasing, whilst the quartz and mica continue to decrease till they disappear, the granite becomes a fine granular greenstone without any visible separation. This change in the nature of the rock is betrayed by *weathering;* for the clove-brown diallage becomes tile-red and frequently of a garnet colour. Towards the mountains, this greenstone passes at last into a coarse granular rock, in which the ingredients of felspar and diallage are beautifully distinct, like the gabbro of the Italians. The felspar of this variety more easily disintegrates than the diallage, although the latter loses its colour sooner. The loose blocks are therefore rough, the diallage projecting when the felspar has been washed away. The stratification is not visible in the coarse granular rock, but in the pure granular greenstone it is very distinct, stretching N. E. and S. W., and dipping 60° towards the N. W.

Not far from Kielvig, a small bay lies between perpendicular rocks, called Little-Kielvig, where the clay-slate passes into mica-slate; for there is no longer any basis to the slate, the whole being a collection of an infinite multitude of shining folia, lying upon one another; not such folia as appear on greywacké-slate, but fresh and scaly, as they usually are in gneiss. In this slate there are several beds of potstone, which is greenish-white, coarse, and frequently splintery, translucent, and very similar to jade, if it were only harder; but it is only semi-hard, and contains small folia of white talc.

The clay-slate only makes its appearance in the vicinity of the sound of Mageröe, and not at the North Cape, where the diallage rock is also wanting. The island of Stappen consists of gneiss; and the nearest rocks of the steep North Cape are of the same nature. This gneiss is more striped than slaty; its mica is black, in very fine folia, which lie single and insulated; and the felspar is abundant, of a pale flesh-red and white, and almost transparent: the quartz is grey and in distinct grains. This rock is certainly not situated above the diallage rock.

"These facts show that the diallage rock here belongs to the remotest members of the primitive formation, and nearly touches on the transition: and this rock is found in the same position in Silesia, Prato, Genoa, and Cuba." *

In this brief sketch of Von Buch's excellent observations on the primary rocks of Norway, sufficient has been extracted to show that the same mineral transitions and the same modes of association occur in this country as characterise the equivalent rocks of Cornwall. We would willingly enter into the minutiæ of this comparison, but they would occupy too much

* Travels through Norway and Lapland, p. 279, *et seq.*

time; and cannot, after what has been said in the former chapters, escape notice on a careful perusal.

In Sweden, also, the granitic masses are said to bear the same relations to the primary slates as in Norway. Most German geologists consider that the granite of Saxony is also similarly circumstanced; and Bonnard and others, contrary to the published opinions of Haussmann, likewise regard the granite of the Hartz, not as the most ancient and fundamental rock of the district, but of a more modern origin, since it is, in many places, regularly interstratified with mica-slate and other crystalline schists, all of which are surrounded by grey-wacké, and appear to repose on the strata of this secondary rock.

In Saxony, however, the appearances of this kind are of a more doubtful nature. As already observed in a preceding chapter, the granite of the Erzgebirge occurs in insulated masses surrounded by primary slates, as in Cornwall; and the latter rocks will be found, in the following details, to present other points of similarity.

Gneiss and mica-slate are the prevailing crystalline schists in this mountainous chain; the former being the most abundant at the eastern, the latter at the western extremity.

The gneiss varies exceedingly in the proportion of its constituent parts, and in the manner in which these are united. At Freyberg it is very micaceous and schistose, being well adapted for economical purposes; whilst at Himmelsfürst, on the contrary, it is of a more granular texture: so that Werner's division of this rock into two kinds may be generally received. The granular variety is often coarsely crystalline, and exhibits frequent passages into granite: and near the town of Schwarzenberg, it contains large pieces of whitish and reddish felspar, having a tendency to a prismatic form, which imparts to the gneiss a porphyritic aspect. In the schistose variety, the component minerals are arranged in regular alternating bands.

This rock contains several subordinate beds, differing from it in composition: thus, quartz-rock at Himmelsfürst; a compound of felspar and tourmaline at Marienbergh; porphyry at Halsbrück; hornblende-rock at Beschertglück; and limestone in numerous places. It also envelops granite in the form of irregular masses and veins, some of which are of considerable size; and one mass, in particular, at Geyer, is well known in consequence of its having been extensively explored for tin ore, in which it abounds. The gneiss of Geyersberg, which encloses this granite, is of the schistose variety, and composed of the common ingredients; the felspar, however, being in a less proportion than usual: its constituents are not indistinctly mixed together, but are individually arranged in small and undulating veins. The granite is fine-grained, and formed of grey quartz, brownish mica, and reddish felspar, which is always the most abundant ingredient; it contains, here and there, a little indurated lithomarge, and shorl; is a very compact sonorous rock, capable of receiving a polish; occurs in beds of from two to ten feet in thickness, dipping 5° to 10° towards the south-east; and is traversed by numerous fissures, which intersect each other at various angles. Between this granite and gneiss there is always interposed a layer of some inches or feet in thickness, which is granitic, but very different from that just described. It contains felspar and quartz in pieces of two to sixteen inches in length: the reddish felspar is still predominant in the mass; the mica is black in less proportion, sometimes in groups of two to six inches in size; and the quartz is often largely developed, crystalline, and compact, and in some parts in distinct pyramids, forming layers which alternate with others of indurated lithomarge mixed with mica. Lastly, this variety of the granitic rock appears always to adhere both to the granite and the gneiss on either side: indeed, these granitic and schistose rocks are so intimately connected that they seem to belong to the same formation.

The gneiss of the Erzgebirge generally passes into mica-slate; so that it is often very difficult to distinguish the latter from the former, at the point of transition. The mica-slate varies much in colour, and in composition; and it is only in a few places, that it exhibits its distinguishing character of interlaminated quartz and mica: when this happens, it abounds in disseminated garnets. This slate contains some subordinate beds of quartz-rock, of hornblende-rock, and of compounds in which garnets and actynolite are very abundant. It is generally succeeded by argillaceous schist, into which it may be seen to pass at Schneeberg.

The clay-slate also sometimes reposes immediately on the gneiss, as at Joachimsthal; where, likewise, it may be seen passing into hornblende-schist. At Johann-georgenstadt, this rock even comes in contact with the granite; but in this position, it is always of an intermediate nature, between mica-slate and clay-slate, and contains layers of quartz-rock.

But the most rare and interesting rock, in the primary schists of the Erzgebirge, occurs at Auersberg, and was first described by Freiesleben. It is composed of quartz and shorl, as mica-slate is of quartz and mica; and it has, therefore, been called shorl-schist: it also occasionally contains mica, chlorite, garnet, and other minerals; but these are not essential. Its structure is striped or ribboned, formed by alternate layers of quartz, and fibrous or granular shorl: the stripes are seldom straight, but for the most part variously curved and undulating. The shorl-schist reposes on the granite: and, although this rock has been only seen *in situ* at Auersberg, there is every reason to believe that it exists elsewhere; since pebbles of it are often found in the alluvial deposits which contain tin ore: and its presence may be regarded as a favourable indication of this metal, as it has hitherto always occurred associated therewith.*

Before concluding the description of the primary schistose rocks, it will be desirable to consider a little more in detail the series in which talc is the characteristic mineral over

* Annales des Mines, tomes 8 et 9.

extensive districts, and not in insulated and subordinate beds, as those already noticed. This series is found well developed in the Alps and in Corsica; and to these we shall for the present confine our remarks.

The rock of Mont Blanc was for a long time considered as a talcose variety of granite. M. Jurine, regarding it as distinct from true granite, gave it the name of protogine; which term has been adopted by Brongniart, and other French geologists. M. Brochant*, after an extensive examination of this part of the Alps, has also concluded that the granitic rock of Mont Blanc is not true granite; but only an extreme variety (more crystalline, and containing a greater quantity of felspar,) of a talcose rock, with which it is associated; and which is very abundant in the adjacent mountains. This talcose formation extends from Mont Rosa to St. Bernard, and to Mont Blanc, and even to Mont Cenis, and, very probably, far beyond these limits; and its most crystalline or granitic variety composes all the highest peaks along this tract. We will not, in this place, stop to enquire whether this rock is the equivalent of granite, and, therefore, referrible to the protogine of the granitic group; or whether it is a member of the schistose group, and best distinguished by the name of felspathic talc-rock, conferred on it by Brochant: but, availing ourselves of the observations of this distinguished geologist, we will endeavour to describe this interesting formation.

The principal and prevailing rock of this series is a talc-schist. Mica-slate is also found in this part of the Alps, and in similar associations, exhibiting frequent passages from mica into talc, from mica-slate into talc-schist, and even into chlorite-schist. The talcose rocks, however, are much more abundant than the micaceous rocks; and thus it is, that micaceous limestones are more rarely met with than the talcose limestones: and this predominance of talc is more

* Annales des Mines, tome 4. p. 283.

remarkable on the Italian side of the Alps. Almost all these varieties of micaceous and talcose slates exhibit different tints of green, sometimes resembling that of chlorite: they very seldom contain distinct scales of mica or talc; but their surface is always more or less glossy, and often presents a striated and somewhat fibrous appearance.

This talc-schist forms the basis of the formation; and, by its combination with other minerals, gives rise to distinct species of rocks. Crystals of felspar are sometimes uniformly disseminated throughout it; when these are of a large size, the rock resembles a variety of gneiss: generally, however, they are very small, and often scarcely discernible, except on the cross fracture of the rock; and even then this mineral would not be recognised, but by tracing its gradual increase in size till it forms distinct crystals. Quartz is rarely present; and when it is visible, it occurs as small grains scattered about in very irregular groups. Hornblende is no where to be met with in this series; that is, in a distinct crystalline form: but it is undoubtedly sometimes mixed with these rocks, for hornblende rocks are found associated in the same mass with felspathic talc-schist, passing into each other by insensible gradations.

The transitions of all these rocks into each other lead one to conjecture, that their different degrees of hardness and tenacity must be attributed to the presence of one or other of these accessary minerals. When they are tough, and at the same time hard, hornblende may be suspected to exist in the compound; when they are very hard, and yet easily frangible, quartz is probably predominant; and, lastly, when they are sufficiently tenacious to be indented by the hammer without breaking, but are not so soft as to be cut by the knife, the presence of felspar is indicated.

Such are the principal talcose rocks of this district: and in those places where they are best characterised, and most abundant, will be found serpentines, either pure or blended with limestone, fine-grained hornblende rocks, crystalline limestones, chlorite-schist mixed frequently with magnetic ironstone, and, lastly, talc-schist; in the midst of which, the felspathic talc-rocks occur, either in the form of subordinate beds, or connected with them by gradually passing into each other.

This felspathic talc-rock is the granitic rock of Mont Blanc. Its principal constituent parts are felspar and talc: the talc is generally of a greenish colour, and often traverses the rock in the form of small veins. This rock has always a tendency to the slaty texture, and even becomes sometimes decidedly foliated; and it is worthy of remark, that the specimens taken from the summit of Mont Blanc present the same character. The only difference between these massive and slaty rocks is, that in the granitoid rock, the felspar most abounds; and in the schist, the talc: just as the analogous case of greenstone and syenite. Quartz is, indeed, also found in this granitic rock, but it is of rare occurrence; and it exists rather as scattered nodules, irregularly grouped, than as crystalline grains uniformly disseminated throughout the mass, after the manner of true granite.

These mineralogical characters, says M. Brochant, conjoined with the geological relations of this rock (viz. its association with talc-schist, serpentine, and greenstone, and, above all, its containing and gradually passing into felspathic talc-schist,) clearly indicate that this rock is not a granite, but only a crystalline variety of the felspathic talc-schist with which it is interstratified. And it may be farther remarked, that the metallic minerals generally occur in true granite, in gneiss, and in mica-slate, in the form of veins; whilst, in the talcose rocks of the Alps, they are seldom met with: and when found, are always in the state of bunches or beds.

Although true granite is not to be met with in the highest parts of the Alps, this rock is not entirely wanting in this mountain range: for the lower parts on the side of Piedmont, from Yvrée, and indeed from Turin, as far as Lago Maggiore, are composed of granite. This rock is well characterised, and, according to M. Brochant, never contains talc: he states, however, that in some places its felspar is decomposed, producing kaolin, or china-clay; and it is, therefore, very possible, that these masses of granite are traversed by beds or layers of protogine, as in Cornwall. This circumstance was, probably, overlooked by this geologist; for he does not appear to have been aware, that granitic masses, as we have already seen, are made up of various distinct rocks: as he states, that the granite of other countries is almost without any intermixture, and does not contain any subordinate rock.

M. Brochant was not able to discover the junction of the true granite with the talcose rocks of the Alps; but in Corsica, which appears to be a continuation of this talcose formation, the nature of this connection is better developed.

M. Gueymard's* account of this island is accompanied by a section, drawn from Ajaccio, through Corte, to Ponte di Golo. The lowest part of the range next Ajaccio is an alternation of granite and eurite: proceeding towards the interior, granite next predominates; but the highest part of the range is composed of eurite, protogine, and hornblende rocks, alternating with gneiss and mica-slate, which gradually give place to protogine, associated with talc-schist and limestone; and these are lastly succeeded by serpentine, talc-schist, and similar rocks in which magnesian minerals prevail.

The details furnished on this subject are not so copious or particular, as the interesting nature of this section seemed to demand. It may, however, be gathered from them, that the beds of granite and eurite are contemporaneous. The granite is also intersected by hornblende-rock and greenstone, in the form both of beds and of veins. These rocks are sometimes disposed in certain directions; but, at other times, they traverse the rock without any regular order. The substance of these veins is often so intimately connected with the rock which encloses them, that they both appear to be of the same age. The granite of the ridge is associated

* Annales des Mines, tome 9. p. 123.

with gneiss, talc-schist, and quartz-rock. It appears again farther towards the west, under similar circumstances; it is generally talcose, and passes insensibly from the protogine of Corte into well-characterised protogine.

M. Gueymard draws a line to separate the primary rocks from the transition; but at the same time states, that such a distinction is not here to be found: for the line laid down rather indicates the limits of certain prevailing rocks, than a separation of geological epochs. The principal rock which succeeds the foregoing, is a stea-schist: it encloses only a few subordinate beds near the coast, but these become more abundant in proportion as the central chain is approached. They consist of blue limestone, more or less veined and crystalline; of ollareous serpentine; of euphotide; of dark-coloured limestone, like that of the Alps; of compounds of quartz and felspar; and, lastly, of porphyry. The quartz-rock and limestone, near Ostriconi, appear to be enclosed in the granitic series; but the author is not quite certain on this point. The granite, however, near Vivario, does contain quartz-rock, and, near the village of the same name, is so intimately connected with gneiss and schist, that they must be all referred to the same epoch.

Such is a brief sketch of the older rocks of Corsica: some of which are extensively worked, and have been long celebrated as furnishing the most beautiful stones for architectural and ornamental purposes. And with this sketch, we terminate our descriptions of the foreign primary schists; to which we shall have repeated occasion to refer hereafter, in our attempts to establish that they are analogous to the Cornish slates.

CHAPTER VI.

ON THE STRUCTURE OF THE PRIMARY ROCKS.

Two kinds of structure, the internal and concretionary. — Both of these also admit of a binary subdivision. — The concretionary being either simple or compound, — and the internal structure either massive or fissile. — Structure of granitic rocks, — developed by the action of the elements, — can also be ascertained by cleavage. — Macculloch's remarks on the spheroidal structure of granite — this structure not confined to blocks, but common to the whole mass. — The general structure dependent on the aggregation of individual concretions. — The layers of granite possessed of determinate bearings like strata. — Structure of the primary schists. — The nature and disposition of strata. — The curvatures and convolutions in the beds of the primary rocks.— Their angular and spheroidal structure, resembling breccia and conglomerates.

The consideration of the concretionary forms of the primary rocks, and of the manner in which these are aggregated together, so as to constitute considerable masses, may appear to some to be here out of place; but it will be seen hereafter, that this subject will furnish some important arguments, in the discussion of the nature of these rocks : at the risk, therefore, of being deemed unnecessarily prolix, we proceed to offer a statement of facts, in many cases, indeed, of a very elementary nature, but requisite to complete the proposed practical sketch of primary geology.

The structure of these rocks may be regarded in two points of view : in the first, as internal; and in the second, as concretionary. To these might be added a third, the mineralogical; but it is, perhaps, preferable to place this under the denomination of the texture of rocks, comprising the compound, the homogeneous, the granular, the crystalline, the compact, the fibrous, the scaly, the porphyritic, amygdaloidal, and other textures, on which it will not be necessary to make any farther remarks.

The concretionary structure is of two kinds: first, that which is exhibited in the integrant masses, of which these rocks are always composed, and which possess forms more or less determinate, such as cubes, rhombs, and spheroids; and which may, therefore, be termed the simple concretionary structure: secondly, the compound, or that which results from the aggregation of simple concretions, giving rise to layers, beds, and other forms of rock-masses, which often partake of the same figure as the parts of which they are composed.

The internal structure is that which is brought to light when we attempt, by violence, to subject the simple concretions to a farther subdivision: it is also of two kinds, the massive and fissile; and generally displays the texture of the rock when this has been obscured by the decomposition, which, almost universally, has taken place on the sides of the concretions near the surface of the earth. The massive and fissile structures mutually pass into each other; and certain stages of this transition have been distinguished by geologists, under the terms tabular, lamellar or laminar, foliated, and schistose. This transition is not a mere abstract idea, for it actually occurs in the same rock, as in the case of greenstone and other hornblende rocks; and many instances have been already mentioned of the passage of lamellar and foliated into compact gneiss, not to be distinguished mineralogically from granite. With these preliminary remarks we shall now proceed to an examination of the structure of the granitic and schistose primary rocks.

The internal structure of the granitic rocks is generally massive, but not always so. The fine-grained granite of Castle-an-dinas, and of other parts of Cornwall, may be easily broken into thick laminæ, as may also several kinds of protogine, of eurite, and of felsparite; and more particularly the latter, which sometimes shews a tendency to a schistose structure. A remarkable occurrence of this kind, in the Isle of Arran, is recorded by Dr. Macculloch. * In many places,

* Western Islands of Scotland, vol. ii. p. 346.

the granite of Goatfell presents solid and continuous faces of rock; while in others, it offers an irregularly laminated structure, very much resembling that which occurs in certain trap rocks, including the syenites and porphyries. The fine-grained granite, on the western side of this mountain, in the Glen of Catcol, is very often even schistose. The laminæ, into which it exfoliates on decomposition, vary in thickness, but may be found so thin, as not to exceed the tenth of an inch. This granite is principally composed of an intimate and minute mixture of felspar and quartz, with small crystals of hornblende, and occasional scales of mica, sparingly dispersed throughout. The schistose structure, therefore, depends in no wise on the mica; and presents no analogy to that of gneiss. And it must not be omitted to notice, that this laborious and observant geologist has remarked, "that the blocks which seem likely to undergo this change, and even those in which it has actually commenced, show no symptoms of future and similar exfoliations; and that all mechanical attempts to produce a new, or prolong an old, fissure, are unavailing; the rock breaking before the chisel or wedge in the ordinary and irregular manner." This circumstance is quoted, because it is at variance with the author's experience: it will, however, be referred to shortly, when the cleavage of granite comes under consideration.

The developement of the structure of rocks, by a partial and incipient decomposition, appears to be dependent on the same principle as that by which the crystalline texture of a saline or metallic mass is disclosed by the action of a weak chemical solvent: but the laws, by which this action is governed, have not been sufficiently investigated. We find, wherever a large section of granite is exposed to the atmosphere, that its surface becomes divided by two sets of fissures, which preserve an exact parallelism among themselves, and which, crossing each other at right angles, separate the mass into blocks of a quadrangular form. Whilst this process is proceeding, the large square surfaces of the granite will be found to be again subdivided into lesser squares, as frequently occurs in the cliffs of the Land's End district: or, if the quadrangular blocks be freely exposed to the action of the elements, they are gradually converted into spheroids of various configuration, by the destruction of the solid angles, as well exemplified in the tors and logan-stones which crown the most elevated hills in granitic districts. "This peculiarity of structure oftentimes produces vast piles of blocks, so regular in their form and arrangement, that they convey a striking resemblance to a gigantic edifice in a state of ruin; and lead us to do homage to the works of Nature, by contrasting them with the petty operations of human skill."

When the structure of the granitic rocks is more particularly examined, it will be found that the concretions, into which they are divided by the intersecting systems of fissures or joints, present various kinds of forms: thus, according as the horizontal joints approach nearer or recede farther from each other than in the cube, tabular or prismatic masses are produced; and as the vertical joints decline more or less from the perpendicular, different modifications of the rhomboid are formed. The figure of the concretions appears in some measure to be connected with the composition of the rock. For example, the common granite (as defined in the preceding pages) exhibits the most perfect cuboidal concretions; the fine-grained granite and protogine disintegrates into tabular masses; shorlaceous granite and shorl-rock often assume the prismatic form; and the rhomboidal structure is characteristic of all the kinds of felsparite, which, however, is not the simple form of this rock, for it separates diagonally into various angular concretions, which renders it a bad building material. These facts are too few to justify a generalization, and are balanced by many exceptions; but which, it must be confessed, have not been subjected to a minute and circumstantial scrutiny: they are, however, sufficient in number to invite more attention than has been hitherto bestowed on this subject.

All these concretionary forms of the granitic rocks, developed by a partial decomposition, suffer a more rapid disintegration at their solid angles, by which the latter are gradually rounded off, and the blocks are converted into spheroidal masses, varying, of course, according to the figure of the original concretions; these are, for the most part, more or less oblate or flattened, though they may occasionally be seen as spheres, so regular, indeed, that they appear to have owed their form to the chisel, and remind one of the granitic shot fired by the Turks at our ships in the Dardanelles.

This universal reduction of the granitic concretions to the spheroidal form, by the action of the elements, — a property which is also common to greenstone, basalt, and other hornblende and crystalline rocks, — is a fact which calls for farther investigation.

Dr. Macculloch is of opinion, that this spheroidal structure is original, and that the cuboidal masses of these rocks are subordinate thereto, being the result of the interference of the contiguous spheres with each other. He conceives "that in a homogeneous mass of fluid matter, crystallization had commenced from numerous centres at the same time; and that, while there was yet space for the formation of successive solid deposits round any set of these imaginary centres, a spherical or spheroidal figure would be the result. As the surfaces of these spheroids approached each other, the successive crusts would interfere, and the remaining intervals would be filled by portions of spheroidal crusts, until the cuboidal figures of all the contiguous masses were completed; thus forming that aggregated mass of cuboids which we witness in the granites of this aspect which remain uninjured in their places. We need not be surprised that this regularity is not more constant, nor the forms more perfect, as we are unacquainted with the numerous circumstances which may determine the several centres of crystallization, or which may interfere with the ultimate regularity of the resulting masses." *

* Geol. Trans., vol. ii. p. 76.

This view of the subject is strengthened by the fact, that it is not an uncommon arrangement in rocks to find not only spheroidal masses, but the constituent parts so disposed around common centres, as to form concentric layers. This circumstance has been noticed in the gneiss of the Western Isles of Scotland, and in the mica-slate of Norway; but the most remarkable instance occurs in the orbicular granite of Corsica.

The spheroidal structure is not confined to the component concretions of the granitic rocks, but is characteristic of the entire masses. Wherever the Cornish granite is exposed by quarries on the side of hills, near the junction with slate (as at Kitt Hill, and in the parishes of Mabe and Constantine), the surface of this rock has not only a rounded form, but it is also traversed superficially, by curved fissures or joints. Indeed, the external form of the country gives indications of this structure; for the broad rounded ridges constitute a peculiar feature of the granitic districts of Cornwall and some other countries, whilst the sharp spiry summits of the Alps and of Arran distinctly mark a different structure, which is confirmed by their being composed of tabular masses, resembling strata placed on their edges. This tabular structure is not only more prone to changes, on account of the comparatively greater exposure of surface, but also because it offers greater facilities for the action of the elements. An excellent example of this nature is presented by the granitic elvans of Hanover Cove, which traverse the slate near the granite of Cligga Point, in Cornwall: the softer kinds of these rocks, and the intermediate slate, have decayed, and been removed by the action of the waves; while the harder kinds of elvans project in thick tabular ridges, about two hundred feet in height, the shattered and serrated forms of which have a terrific aspect when viewed from the sea. But to return to the spheroidal structure: there is one fact which is opposed to its being the original or fundamental form of granite, and that is, that the granite is not only traversed by systems of parallel joints, as already stated, but is also capable of being cleft in directions corresponding therewith; so that, whether the spheroid be on the large or small scale, it can be subdivided into cuboidal forms. There can be no doubt, however, that these lesser cubes would, on exposure to the air, be also reduced to spheroids; so that it is a difficult matter to decide whether the latter is the original form, or whether it is accidental, resulting from the solid angles exposing a greater surface to the elements; or, whether the cohesion being weaker in those parts, may oppose less resistance to a chemical change. If the decomposition continue after the spheroid is formed, it then takes place uniformly over the whole surface, which consequently exfoliates in concentric layers.

Dr. Macculloch has made some interesting observations on this subject, suggested to him by observing in the British Museum, granitic columns from Leptis, in Africa. "I was surprised to find," he says, "that the shafts of these columns were in the act of desquamation, casting off crusts precisely similar to those which occur, in many cases, in natural blocks of granite; but in this instance the detached crust is not decomposed, and appears scarcely changed from its original state, except in tenderness and fragility." * This shows that the atmospheric influence may, under some circumstances, only produce a general and superficial change, just as a metal plunged into a corrosive acid, and immediately removed, will be uniformly corroded; but if allowed to remain in for some time, the prolonged action of the agent will show that the oxidation has been more energetic at certain points, whereby the crystalline structure of the metallic mass is developed.

From these facts it is not improbable, that the spheroidal forms, so commonly exhibited by the crystalline rocks, are varieties of original structure, the result of some peculiar mode in which their integrant particles have been aggregated

* Journal of Science and Arts, vol. xiii. p. 238.

together, and which appear to subsist in the same mass, in conjunction with various cuboidal and prismatic arrangements.

The fissures or joints which occur in the upper part of granitic rocks, are produced either by direct exposure to the atmosphere, or by the percolation of rain water; and it has been stated, that they unfold the form of the concretions of which the aggregate mass is composed, just as the fundamental forms of a crystalline mass are displayed by the partial action of a chemical solvent. And this analogy is confirmed by the fact, that in both cases the same result may be obtained by mechanical means; thus, large blocks of granite, or the mass of this rock, at depths where the joints are no longer visible, may be cloven into cuboids, by means of several wedges applied on the same line; and in this manner all the granitic rocks may be divided into blocks corresponding in form to those developed by the action of the elements. According to the case already related, concerning the schistose granite of Arran, by Dr. Macculloch, this does not always hold good; but this discrepancy may, perhaps, be attributed to the imperfection of the mechanical power which he employed, conjoined with the refractory nature of the rock operated on. The geologist would not readily arrive at the fact, that common granite can be separated into cubes; for with his hammer and wedges he can only break off irregular fragments: but the quarryman, by first boring several holes on a given line, at an equal distance from each other, and then alternately striking wedges placed therein, can cleave the granite into regular quadrangular masses; and, in like manner, slate may be raised in large tabular slabs by the simultaneous application of many broad wedges, whereas the geological tools would only shiver the slate into foliated fragments.

That the cleavage of granite into regular forms depends on the structure of this rock, is proved by its only taking place in certain directions corresponding therewith. The workmen are well acquainted with this fact, and therefore never attempt to break the rock in a line diagonal thereto; and geologists are indebted to them for some curious information on this subject, which has been recorded by Mr. Enys. The granite of Penryn is principally composed of two kinds: one is a hard and compact rock, which is extensively worked and shipped for the London market. It runs in parallel ranges, bearing N. E. and S. W., through the other kind, which is softer and of a coarser texture. The hard granite is cloven into quadrangular blocks; and it has been ascertained by long experience, that the cleavage cannot be effected in every direction, but only with regularity in three, and that each of these require a different degree of force: thus, if the horizontal cleavage demands a power denoted by two, the perpendicular cleavages, crossing each other, will be in the proportion of three and five; the latter commonly intersects the larger felspar crystals, whilst the former is parallel therewith, and may be termed the longitudinal cleavage. Near Penryn the last mentioned line of cleavage runs N. N. W. and S. S. E., varying 15° or 20° either way: it generally coincides with one of the vertical natural joints, though in many instances it does not correspond therewith, but crosses them often at an angle of 30° or 40°.* This interesting fact cannot fail ultimately to lead to some important information, as it will direct the attention of geologists to the condition of the granite of other countries in this respect.

This subject has not altogether escaped notice, as will be seen in the following extracts; but it does not appear to have suggested the idea that the layers into which granite is divided by such seams having a determinate bearing are similar to the beds of stratified rocks, nor has it given rise to more extended enquiries.

"The granite of Reville, in the department of La Manche," says De la Beche, "generally resembles that of Dartmoor, containing large porphyritic crystals of felspar. It splits in

* Lond. and Edin. Phil. Mag., vol. ii. p. 321.

two directions; one east and west, the other north and south; and forms large rhomboidal blocks: some few groups of granite rocks, on the sea-shore, are split into similar blocks, which have not the same direction. The granite at St. Vaast and the opposite island of Tatihou is somewhat different from that of Reville, though evidently in connection with it; it is split into similar blocks, and the fissures are in the same direction with those at Reville; in both places it is traversed by granite veins, of which the predominant ingredient is flesh-coloured felspar."*

Similar appearances have been observed in the granitic district of the east of Ireland. "In the quarries of Golden Hill," says Mr. Weaver, "the granite is divided by smooth parallel seams into strata, three, four, five, and more feet thick, ranging north and south, and dipping E. 75°. These strata are sometimes, though rarely, intersected by cross joints, under an oblique angle, which are mostly parallel to each other: in such cases each stratum becomes naturally separated into tabular or columnar masses of a rhomboidal form." "In Glencullen, the granite is also divided into great massive strata, which range 20° east of north and west of south, and dip into the mountain to the westward, at an angle of 70°. And on the Dalkey coast, a large insulated granite rock, in its natural position, is composed of parallel layers from one foot and a half, to three feet and a half thick, ranging north and south, and dipping 70° east."† The numerous instances on record, of the stratification of granite, are of the same nature, the mass being divided by seams into regular beds: thus, "the granite on the French coast, near the mouth of the Loire, exhibits this appearance of stratification; the beds running S. E. and N. W., dipping towards the S. W., under the sea, at a moderate angle of inclination."‡

From these facts we arrive at the important conclusion, that the granitic rocks are not rude and shapeless masses, as

* Geol. Trans. (New Series), vol. i. p. 87.

† Geol. Trans., vol. v. p. 138. ‡ Annales des Mines, tome iv. p. 25.

is commonly supposed, but that the structure and arrangement of their parts exhibit as great marks of order and design as any department of the mineral kingdom. Though the three systems of cross joints often afford indications of apparent complication and disorder, yet we can frequently detect a more regular arrangement of layers or beds than is to be found in some kinds of gneiss. We also learn, that in Ireland these granitic layers are inclined at various, though elevated, angles; and the same circumstance is of very common occurrence in Cornwall, the dip varying from 45° to the perpendicular; and in these cases the other joints are so disposed, as to divide the layers into rhomboidal concretions. And since the different modifications of this form have some connection with the mineral composition, as already stated, it might be expected that the inclination of the layers would correspond with the nature of their component concretions; and thus the lesser angles more generally belong to eurite and felsparite; the higher ones, to shorl rock and fine-grained granite; whilst the layers of true granite are sometimes perpendicular.

In thus asserting that the beds of granitic rocks exhibit regular bearings, both of *strike* and dip, it must be clearly understood that these can only be occasionally detected; and are often, as in the case of the schistose rocks, complicated and obscured by the curvatures of the beds. If we examine the sea-shore and cliffs of the Land's End district, the parallel seams of the granite will be generally found more or less serpentine; and frequently their interference with each other will produce beds tapering away to a certain point, and then enlarging, or even terminating in wedge-shaped masses. This form of the granitic beds holds good both in perpendicular and horizontal sections; and it will be soon shown that the schistose rocks are subject to the same *apparent* irregularities.

It is particularly worthy of remark, that the beds of granite exhibited in the cliffs of the Land's End district are always more or less inclined; they often indeed present perpendicular faces which, being traversed by upright lines, represent vast piles of columns: but these sections cross the beds at a considerable angle, and their nature may be easily detected by a close inspection of the mass, when they will be seen to result from the rhomboidal concretions being so arranged that one of the three parallel systems of planes of which they are formed, has a perpendicular position. This prevalence of the rhomboidal structure, in the cliffs of this district, is an interesting fact, because the granite is here always at or near the junction with the slate, and generally exhibits such a variation in its mineral composition from the central masses as characterises this rock when it comes into contact with the primary schists, and on which account it is often difficult to decide whether the rocks at the junction be granite or slate, without putting them to the test of the hammer.

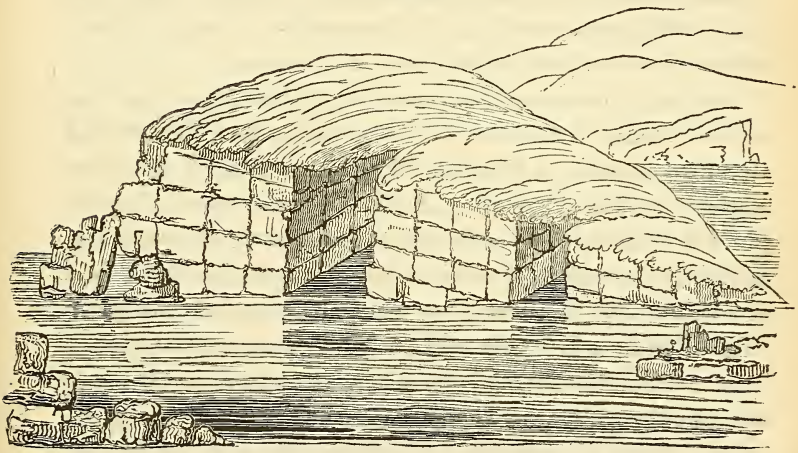
Now in all the cases just quoted, of the bearings of granitic layers or beds, in France and Ireland, the same rhomboidal structure prevails, as indicated by the beds dipping at various angles; and the granite, in all these places, occurs near the junction with the slate. It becomes, therefore, an interesting enquiry to ascertain, if possible, the limits of this structure; and under what circumstances the granite assumes a regular cuboidal structure. It is well known that the central part of a mass of granite is not wholly of the latter kind, because it is traversed by beds of eurite, felsparite, and other granitic compounds, which are composed of rhomboidal concretions. It will, perhaps, be found that cuboidal blocks are not so common or characteristic of granitic rocks as is generally assumed.

Before concluding this topic it may be observed, that the granitic beds necessarily dip at several angles, according to the kind of rhomboids of which they are composed, and to the position in which they are placed: thus, in granitic cliffs, the rock will be commonly found to present a perpendicular face, and two inclined ones; one of the latter dipping at a very elevated angle, and the other at an angle of less than 45°: —

bearing this in mind, and making allowances for the spheroidal tendency of the mass, and the curvatures of the layers, a regularity may be generally detected, not inferior to that of the crystalline schists.

This structure is more or less visible in most published sketches of granitic cliffs; more particularly if the sea has excavated some portions of the perpendicular layers, in consequence of a different composition rendering them more susceptible of decay and degradation. We have attempted in the subjoined figure to convey an idea of this arrangement, having for this purpose intentionally exaggerated the regularity of the lines.

Fig. 4.



The lines corresponding with the gentle declination of the nearest hill towards the point, mark the manner in which the inclined face of the rhomboid slopes in one direction; while the greater slope of the hill towards the cliff is denoted by the lines on the sides of the indentations of the cliff, which run parallel therewith.

Concerning the structure of the primary schistose rocks a few remarks will suffice. It may be divided, as in the case of granite, into the concretionary and the internal; and the latter is only to be distinguished from that of granite by its foliated modifications predominating over the massive, whereas it is the reverse in granite.

The various kinds of structure so frequently pass into each other in the same mass, that it is oftentimes very difficult to observe where the one begins and the other ends. When the rock has a compact texture, but more particularly if it be crystalline, it most commonly exhibits a massive structure; and as it gradually becomes more and more fine-grained and homogeneous, it generally acquires a proportional degree of fissility, acquiring at last a perfect slaty structure: on this account it is often impossible to draw a line of demarcation between the true slates and the massive, crystalline, and granitic rocks, with which they are associated; since they gradually pass into each other in their mechanical arrangement, as well as in their mineral composition. This is not only the case in Cornwall, but in all primary districts. It would lead us into too many details, and into many repetitions, if we were to enter fully on this subject; let it therefore suffice to quote one example from Dr. Macculloch, on Scotland. "The primitive greenstone and greenstone-slate consist of mixtures of felspar and hornblende; in the latter case disposed in a laminar form, and in the former, without that regular structure." "These greenstones constitute a class of rocks entirely different from those that are intruded amongst the regular system of secondary strata; and have evidently been formed together with the gneiss and mica-slate which they accompany; and are, like them, referable to the same epoch, never intruding to their disturbance, but occupying situations and maintaining characters in every respect conformable to them."*

Thus we find that the internal structure of the primary rocks, both granitic and schistose, is of the same nature; the only difference that can be observed is, that the massive structure prevails amongst the former, and the latter rocks

* Geol. Trans., vol. ii. p. 393.

are more frequently fissile. Let us then entirely overlook the nature of the internal, whilst we examine the concretionary, structure of the schistose rocks.

In Cornwall, all the varieties of rocks belonging to the schistose group are composed of rhomboidal concretions; these exhibit various modifications, and are more distinctly formed in some rocks than in others, especially in those which are principally composed of compact felspar. This structure is not only detected by the fracture, but it is also, on a large scale, developed by a partial disintegration, by which parallel systems of fissures or joints are produced, as in the case of granite. These are sometimes not so evident, and are complicated by the degradation of the slate, in the direction of its internal laminæ. One set of these fissures may be often seen traversing these rocks, in a perpendicular manner; as shewn by the smooth upright surface of some cliffs, and by the regular parallel surfaces, when an intermediate layer has been removed by the action of the elements. And, indeed, the same fact may be very frequently observed in quarries. In these cases, if the adjacent parallel joints be disclosed, they will be found running in opposite directions, the one at a greater angle than the other. This is owing to the form of the layers, resulting from the aggregation of rhomboidal concretions; and the nature of it will be plainly illustrated by so placing a rhomboid that two of its sides may be perpendicular. In this manner are arranged layers of rocks, that are sometimes massive and sometimes fissile; or which, indeed, individually partake of all the forms of internal structure.

There can be little doubt but that the primary slates of other countries possess the same structure; that we have not many facts in corroboration of its universal occurrence may perhaps be, in some measure, attributed to these rocks not being found under circumstances so favourable for observation as those of Cornwall. That this structure, however, is not peculiar to the latter country may be gathered from the following statement:—"In the course of the operations attending the driving of levels and sinking of shafts in Cronebane and Tigrony, I have observed," says Mr. Weaver, "that the slaty rocks (whose general range is nearly N.E. and S.W., and dip S. E. at an angle of 65°) are divided into great beds, commonly about five fathoms thick, by parallel seams or joints, which intersect the inclined plane of the clay-slate at right angles, dipping 25° towards the N. W. These seams are open fissures, which will sometimes admit one or two fingers, and at other times scarcely the blade of a knife. In their progress they pass uninterruptedly through all the beds and contemporaneous veins included in the slaty rocks, dividing them, and sometimes producing, as it were, a sensible alteration in their disposition, though to no great extent. This tendency towards a division into horizontal beds (independent of the slaty structure) may also be observed in several parts of this district." *

From the preceding observations on the arrangement of the Cornish schistose rocks, it is evident that the dip of the layers or strata may be referred to more than one direction: which of these is to be regarded as the true one? This is a question not easily answered in a satisfactory manner; and yet we find that geologists have not often expressed any hesitation in determining this point, though one of great importance, as many of the arguments advanced in favour of the prevailing theory depend on the direction and the inclination of the primary strata.

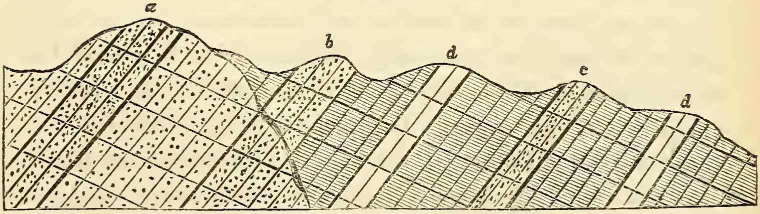
In Cornwall, the choice of the true dip lies between the two largest faces or surfaces of the rhomboidal layers, which run in the same direction, most commonly N. E. and S. W., but dip at opposite angles. In the description of this county, published in the Cornish Transactions, that surface of the layer which is parallel with the laminæ of the rock has always been selected: this, indeed, generally appears to be the most

* Geol. Trans., vol. v. p. 217.

extended surface; but it may be in some measure deceptive, arising from the formation of seams or fissures between the laminæ, as well as between the layers or strata. Adopting, however, this method, the dip of these schists is commonly found to be from the granite in the vicinity of this rock, and at a distance therefrom, very frequently in an opposite direction: it is, however, very various; and if the inclination does follow any general rule, it is that of the great curvatures of these rocks, with which it almost universally corresponds. The angle of the dip scarcely, in any instance, exceeds 40°, generally fluctuating between 25° and 35°: and the amount of this angle bears no relation to the vicinity of the granite; for next this rock it is sometimes great, at others, exceedingly small.

If the inclined surface of the layer, which dips in the opposite direction, were adopted as the surface of the stratum, then the slate of Cornwall would have an inclination varying from 45° to 75°, and even approaching still nearer to the perpendicular. There is one consideration, that might induce some to prefer this view of the case; viz., that the layers of massive crystalline and granitic rocks very commonly lie in directions parallel thereto. Thus, the elvan courses, near the granite, almost uniformly dip towards this rock, whilst the laminæ of the slate are disposed in an opposite direction, so that they often appear to be intersected by the elvans. The following diagram will, perhaps, render this arrangement more intelligible:—

Fig. 5.



a, porphyry in granite; *b*, the same rock traversing both slate and granite; *c*, the same in slate; *d*, *d*, *d*, compact rock in slate.

Now on what principle can it be decided which of these two directions, exhibited by the fissures or joints traversing the schistose rocks, is the true dip of the strata. In the secondary rocks, the laminæ of the slate are frequently found at considerable angles to the strata, as determined by the alternation of the slate with other rocks; and, therefore, it may be given in favour of the greater angle inclining towards the granite, as in the above diagram: but it may be stated that, in adopting the other, we are not singular; for Professor Sedgwick, in his excellent communications, published in the Transactions of the Cambridge Philosophical Society, has assigned the same dip to the Cornish strata. This subject will be reverted to again hereafter; at present, we must continue the description of the primary slates.

Complicated as the structure of these rocks may have appeared, in the foregoing details they have hitherto beeen only considered under their most simple forms; for, in addition to what has been already said, it must be stated that all the schistose rocks are more or less curved, not only in the direction of their beds, but also at right angles thereto. These curvatures are sometimes contorted, but never to that degree which is so characteristic of gneiss and mica-slate.

In looking down on the slate district from a granitic eminence, the surface will be found to consist of two systems of curves, which cross each other at right angles; and wherever the subjacent rocks are laid bare, they exhibit a corresponding curvature. These curves are not, indeed, always parallel with the surface; for the latter has been more or less modified by the operation of atmospheric and other agents: thus, the sides of some hills are serrated or irregular, by the protrusion of some strata more indestructible than those with which they alternate; and some valleys are not concave, but flat, from the accumulation of detrital deposits. But such variations may be easily allowed for, and, indeed, are not perceptible when viewed at a distance: the general external appearance, though modified, accords well with the internal structure of these rocks. That this circumstance is not so apparent in other countries, may be attributed to the presence of secondary and tertiary rocks, as well as of recent debris, by which the surface has assumed a new and different feature.

For farther particulars on this subject the Cornish Transactions may be consulted; but we must not omit to observe, that the laminæ of the schist very frequently correspond with the ascending and descending curves, which are parallel with the granite: or, in other words, in traversing the slate at right angles with the granite, the laminæ dip in the same direction as the slopes of the hills: and that the strata forming the limb of the curve nearest to the granite are commonly thinner than those on the other side of the curve, and are more abrupt, dipping at a greater angle; in consequence of which structure, it often happens that the thin and highly inclined strata, at the summit of the hills, have been entirely degraded; whilst the more extended strata are persistent, exhibiting an underlie conformable with the granite. In like manner, the small islands on the coast, which frequently consist of the upper parts of such individual curves, have sometimes lost the highly inclined layers by the action of the waves, only retaining those strata which dip from the shore, and which correspond, or not, with the inclination of the nearest mainland, according as this is composed of the ascending or descending portion of the curves. The north coast of Cornwall, particularly at Portreath, and the adjacent coves, well illustrates this disposition of the strata.

It is time, however, to turn our attention to the structure of the primary schistose rocks of other countries.

The disposition of the beds of gneiss in the Western Isles of Scotland is very irregular, more particularly those of the granitic species of this rock. Towards the southern and western parts of Coll, the gneiss is often arranged in regular beds, of which the alignement can be traced for a considerable space, straight and free from all that disturbance which marks the beds of Tirey. Towards the middle and northern end of this island, however, all order disappears, and the masses are disposed in a dislocated manner. The direction where it can be traced is north-easterly, and the dip towards the east; as is pretty generally the case in these islands. The angle of the dip is various, often reaching to 70° or even to 80°, and seldom declining so low as 15°. In Barra, also, the beds of gneiss can rarely be traced for more than a few yards together in a straight line: they are commonly bent, and even much contorted, while their inclinations to the horizon are very irregular. In East Rona, as already noticed, the gneiss often dips in opposite directions. In short, in these islands, as on the mainland, the gneiss sometimes cannot be detected in the form of beds; and when the beds are apparent, they exhibit all the complication of direction and dip which might be expected, from their being curved on the great scale in two lines, which nearly cross each other at right angles, besides the lesser and subordinate curves, to which the larger ones are continually subjected. To this structure of the primary schistose rocks, assisted by the action of the elements, may be attributed the parallel arrangement of these ranges of islands, and the subdivision of these ranges into the individual isles. The strata in the southern clusters are, indeed, more regularly disposed; but still, on the great scale, they present the same characters: their composition is also different, consisting in a great measure of clay-slate which, at a distance from granite, is commonly arranged with a greater degree of regularity than gneiss.

Thus Macculloch* informs us, that the prevailing directions in the shores of these islands will be found to correspond in a great degree with the direction of the strata of which they are composed, and to vary in a great measure according to the changes in the lines of bearings; and a similar general correspondence will be discovered on the mainland between the direction of the strata and the general forms of the

* Western Islands of Scotland, vol. ii. p. 298.

shores. If the lines of direction are connected throughout, it will be seen that they are curved; and the reality of the curvature is proved by its taking place, not only in the intervals between these islands, but even in the isle of Luing itself. This curvature, however, is not so great as to implicate all the parallel strata; as it is not found in the Garveloch Isles, which lie immediately to the westward of Luing. Although the direction of these schistose strata is thus constant, with certain trifling exceptions, which must be rather viewed as temporary undulations than as serious deviations from their general course, the dip is in different places not only various in quantity, but also reverse in position. In Gigha, it is to the westward; while it is to the eastward, not only in Isla and Jura, but in all the northern isles. To whatever quarter, however, the strata dip, the angle of inclination is seldom less than 20°, and rarely exceeds 60°. Over a considerable tract on the mainland the mica-slate and clay-slate series accompany each other, alternating together, and exhibiting frequent transitions which terminate upwards by the predominance of the clay-slate. These stratified rocks extend in one belt from the easternmost point of Scotland to Bute, running N.E. and S.W., and dipping towards the east; and they are subject to no other deviation or irregularity, than those slight undulations from which none of the Scottish strata are exempt. Now these two series of slate are also continued into Arran; but their continuity is there interrupted, for a certain space, by a mass of granite. They are no longer parallel to each other, nor do their strata possess the same direction or dip. Indeed, such is the apparent confusion, that the dips cannot be exactly ascertained; yet it is evident, on comparing a great number, that the predominant tendency of the whole is conformable to the surface of the granite on all sides; or, in other words, that the strata repose on the mountain mass. And since the micaceous series prevails on the south-western side of the granite, and the argillaceous on the north-eastern side, it is evident, that the strata of these series respectively dip to opposite points of the compass.

Such is the disposition of the primary strata on the western coast of Scotland, which is similar to that of the analogous rocks in Cornwall; and on referring to the details on Norway, in the fifth chapter, the gneiss, and other schistose rocks, will be found to exhibit the same characters: we will, therefore, conclude this topic with one more example taken from the east of Ireland.

It has been remarked by Mr. Weaver, "that, in following the line of the two Avons, the Daragh and the Avoca, from the granite chain on the west to the sea on the east, the slaty rocks gradually acquire a higher angle of elevation. In the glens, the angle of apposition is from 20° to 25°; in the meridian of Cronebane, the angle is 65°; and nearer to the coast, it varies from 70° to 80°. On the western side of the mountains, this order is in general inverted, the highest angle being in the vicinity of granite, and the lowest most remote from it, with this additional distinction, that the dip of the slate is commonly opposed to that of the granite declivity on the western side; while, on the eastern, their position is more conformable to the declivity."* In order to show the nature of these dips, it will be desirable to enumerate several examples from the same author.† Thus, we find, that on the eastern side of the range, the mica-slate at Killiney Bay leans against the granite, and dips from it at an angle of 80°; at the eastern side of Rochetown road, near the martello tower, it dips in the same direction at 40°; whilst, on the eastern brow of Rochetown Hill, in a natural hollow in the granite, its dip is 75°: on the southern side of the Scalp, this slate rests on the granite, inclining towards the S. E. at 35°; but the general mass ranges through the hill, dipping N. of E. at 40°: at Maulin Hill it dips on the summit 25° towards the S.E.; but on the west, near its

* Geol. Trans., vol. v. p. 178. † Idem, 140. *et seq.*

contact with the granite, only 5°: and in the adjoining glen of Balveagh, a precipitate mass of this slate reposes on the granite in a nearly horizontal position: in Glenmacanass, the mica-slate has various dips in different places, varying from 20°, 25°, to even 70°: on the western side of the mountain range, the mica-slate adjoins the granite at Glenismaule, and dips towards the N.W. at 75°; and near the same spot, 52° in the same direction: at Seefiniane, it dips 45° north: in the northern part of Seechon, it inclines towards the south at an angle of 75°; in this neighbourhood there appears to be a gradual reversion in the direction of the dip, as the slate is seen in a nearly horizontal position, inclined at an angle of 45°, then 52°, and, lastly, of 75°: at the eastern side of Brisselstown, it dips 65° towards the east: at Kilranela Hill, the mica-slate is remarkably contorted, dipping near the summit at 30°; while, on the eastern side of the hill, the dip is 65°: in Baltinglass, Tinoran, and Manger Hills, the inclination of this slate is generally about 60° towards the N. E.; and near Graige, on the eastern bank of the Barrow, it dips 65° to 70° S.E."

From these statements we learn, that in Ireland, as in Cornwall, the crystalline slates dip at very different angles, not only in distant places, but also within a narrow compass, even on the side of the same hill, owing to the curvature of the strata: and, moreover, that the strata are variously situated; reclining, in some places, in positions conformable with the granite; and, in others, they are so disposed, that if the dip were prolonged, they would abut against or pass under the granite. Although, however, this disposition in the direction of the dip often corresponds with the curvatures of these rocks, it must not be considered as dependant thereon; since these variations of dip often occur when the rocks are disposed in straight and regular beds.

Details on this subject might be multiplied to a great length, for the convolutions of rocks has always been a favourite object of research to the geologist, but the purpose of this work does not require it; we shall, therefore, conclude with observing, that the curves are sometimes "simple, like the superficies of a cylinder; at other times double, like that of a sphere;" and sometimes they are angular or contorted, exhibiting the most complicated sinuosities. And these circumstances of curvature are not confined to a mass of strata, but are possessed by individual strata alternating with others, that are straight and regular; and may be often observed even in the laminæ, or smaller concretions, of which a stratum is composed.

There yet remains another variety of structure to be described, not uncommon among the primary rocks, and which is generally considered as a proof of a mechanical origin. Without, however, expressing any opinion on its nature, let us in this place confine our attention to a description of this structure, which is characterised by an aggregation of angular and spheroidal concretions.

It has been already stated, that, on the large scale, the granitic rocks appear to be composed of spheroidal masses; and that, during disintegration, the open seams divide the mass into tabular and angular portions: but the structure now under consideration is distinct from this, being confined to the individual concretions of which the mass is composed.

First, as regards the spheroidal or conglomerated structure. An instance of this nature has not as yet been noticed in the Cornish granite, with the exception of those crystalline nuclei, of a dark colour and fine grain, which occur here and there insulated in the granite, and which, indeed, if sufficiently abundant to predominate over the containing rock, would exhibit this kind of appearance. In the globular granite of Corsica, however, we have a noted example, in which the constituent minerals are arranged around certain centres in concentric laminæ. In the schistose rocks, this structure is of a more frequent occurrence. In the gneiss of Coll, nodules of hornblende-rock are completely enveloped in the laminæ of the former rock, which are every where bent over them, as if they had, in a soft state, been moulded on the previously indurated concretions. * So likewise near Drontheim, Norway, in a rock intermediate between mica-slate and clay-slate, folia of mica surround kernels, which are very hard and compact, and appear to be a granular mixture of compact felspar, a little quartz, and fine scales of mica. The kernels, with their envelope of mica, are of various sizes, sometimes equal to two or three feet in diameter: these concretions lie close together, forming whole rocks. In Cornwall, the compact variety of chlorite-schist near Relistian mine exhibits this conglomerated structure: its nodules are not globular, but flattened, and are composed of concentric layers, the outer ones being softer and more chloritic, the central more compact and crystalline.

Many examples of this conglomerate have been recorded: that of Valorsine is particularly noted, and is regarded as a detrital rock; but if it alternates with gneiss, as has been stated, it is probably of the same nature as those just enumerated. "The lower part of the Col de Balme, according to Saussure, as quoted by Dr. Kidd, is a moderately grained grey granite; above which are rocks intermediate to gneiss and mica-slate: higher up are beds of a grey and sometimes greenish slate, containing a great quantity of rolled pebbles, some angular and others rounded, varying from the size of sand to masses of six or seven inches in diameter. Some of the beds are very thin, remarkably fine grained and micaceous, and entirely free from pebbles; others are of considerable thickness, and filled with pebbles." Brongniart, also, in the Cotentin, in Brittany, observed a similar fact. A series of granitic and syenitic rocks is followed by a shining argillaceous slate of a greenish colour, the laminæ of which gradually becoming more and more undulated, and traversed by veins of quartz, and penetrated with oval nodules of the same

* Western Isles of Scotland, vol. i. p. 64.

substance, the rock passes insensibly, without any change in its structure, or in the degree of inclination of its strata, into a steatitic schist. And he remarks, "that this schist also contains numerous nodules of quartz, which, being penetrated by the matter of the talc, cannot be considered as rolled pebbles, but as nodules cotemporaneous in their formation with the rock itself." * Lastly, Mr. Weaver states, that, near Cronebane in Ireland, the clay-slate occurs in almost every stage of union with quartz, which varies in size from large compressed lenticular nodules to the smallest grains, terminating in a most perfect intermixture of the quartz with the substance of the slate. These nodules are arranged parallel with the direction of the strata; and they often terminate in thin edges, diffused between the laminæ of the slate.†

The primary rocks which are composed of angular concretions, are of more frequent occurrence in Cornwall than those of a conglomerated structure. The quartzose varieties of the granitic rocks, in which quartz predominates, often exhibit an angular appearance; and this is much more distinctly developed in the same species of the primary schists. The layer of felspathic rock, which is worked for tin ore near the Indian Queens, in the central district, so abounds in small angular portions of different colours and texture, that it resembles a coarse *lime-ash floor:* this rock appears to be a regular *elvan-course*, equivalent to the beds of porphyry which are associated with the Cornish slates. At Huel Virgin mine, near Marazion, one of the beds of slate is intersected by small irregular veins of flesh-coloured felspar and quartz; and, in some parts, the former so predominate in the mass, that the slate is divided into small angular portions. This rock assumes every variety of form, according to the proportion of its constituent parts, exhibiting a most perfect likeness of a brecciated marble. This bed, according to Mr. Henwood, is considered as one of the *lodes* (as in the case of Relistian

* Geological Essay, p. 83.

† Geol. Trans. vol. v. p. 171.

mine), on account of its being metalliferous. And it is, indeed, worthy of observation, that the contents of the Cornish veins are commonly arranged in a brecciated manner, consisting of quartz and of angular pieces of the adjacent rock; whilst the conglomerated structure is of rare occurrence, but has been observed in veins traversing the granite of St. Just, as well as in those which are situated in the slate.

A remarkable instance of this kind was seen by Macculloch in the island of Coll, near Ben Feoul. Distinct beds of mica slate alternate, there, with gneiss: one of these abounds in fragments of quartz, so as to form a breccia.* Whether a similar kind of rock in Rasay is really a variety of gneiss, or a true fragmentary rock, is not very apparent. "It entirely consists of fragments of gneiss, broken and reunited with very little change of character: it can scarcely be separated from the principal rock." In the same situation a breccia "is formed of dark red felspar and hornblende-schist equally mixed in distinct fragments, and producing, from the contrast of colour, a very peculiar appearance."†

At Ben-na-chie, in Aberdeenshire, says Dr. Macculloch, the quartz-rock in contact with the granite exhibits an interesting appearance. "The regularity of the stratification is disturbed, and, in many places, the strata are fractured and displaced. Where the fractures are considerable, the parts are sometimes reunited by minuter fragments and by crystalline quartz; and, in many places, these fragments are so numerous, that the whole mass forms a breccia, or an angular local conglomerate of a peculiar character."‡

The gneiss, near Formo, in Norway, says Von Buch, rises to a great thickness; and in the Rostenberg, and in the ravine towards Lessöe, it becomes very remarkable in its composition. The gneiss, here, generally abounds in mica, which is not scaly foliated, but in large continuous folia; and it also contains

* Western Isles, vol. i. p. 63. † Idem, p. 247.

‡ Geol. Trans. New Series, vol. i. p. 58.

numerous beds of quartz: throughout this rock appear, in every direction, considerable pieces of gneiss in which the felspar predominates, the mica being only in isolated folia, and the quartz in very small quantity. The mica in these pieces only gives rise to straight and parallel streaks, while in the surrounding gneiss it renders the slaty texture more strongly marked and distinct. These pieces are all angular, and most of them even quadrangular; and are a foot and upwards in size: they are very thickly heaped together, but still in such a manner that the intervening mass of gneiss may always be distinguished. The streaks of different pieces lying near each other are often parallel; but they also frequently take different directions, and do not, therefore, follow the direction of the cleavage of the basis. "This wonderful rock is not a conglomerate; the basis is too distinctly characterised as gneiss: but it must be owned that this appearance bears some resemblance to the manner in which the pudding-stone is found in gneiss at Valorsine, and in the lower Valais, according to Saussure. It appears to be an older gneiss which was destroyed during the formation of the newer gneiss."*

Mr. Weaver has remarked, that the apparently *brecciated* rocks are connected by insensible gradations with mica-slate, and even with the fundamental granite itself: and is of opinion that neither the mere occurrence of matter mechanically divided in the composition of rocks, nor the curvatures or inflections which their strata sometimes display, entitle them to a place among the transition formations; for these are characters common to all classes of rocks.†

Having now examined the structure of the primary rocks, we are the better prepared to enquire into the nature of the relative position of the granitic and schistose rocks.

* Leopold Von Buch's Travels in Norway and Lapland, Jameson's edition, p. 94.

† Geol. Trans. vol. v. p. 196.

CHAPTER VII.

ON THE RELATIVE POSITION, AND ON THE NATURE OF THE GRANITIC AND SCHISTOSE ROCKS AT THEIR JUNCTION.

Position of the primary schists next granite. — They extend far over this rock through the transverse valleys in Cornwall. — The mica-slate of Ireland similarly situated, capping the granitic mountain of Lugnaquilla. — The Cornish strata skirt the granite in an irregularly undulating curve. — The same arrangement obtains in the isle of Arran, — in the north of Scotland, — and in the Alps. — Dip of the strata at the junction, — in Arran, — in Cornwall, — in Galloway, — apparently irregular — not so — dependent on the structure of the primary rocks — illustrated by sections. — The anticlinal axis of primary districts — said to be simple in each geographical range — not so in the Ocrynian range, nor in the Pyrenees. — *Composition of granite and primary schists at their junction,*—in Cornwall, — near Cherbourg,—in Ireland — in Iona and Mull, — in Glen Tilt, — and near St. Paul Fenouillet in the Pyrenees.

It has been already stated that the primary rocks have an undulated structure; and, that the curvatures of these rocks cross each other at right angles, thus producing, at the surface, two parallel systems of valleys. If we examine those valleys, in Cornwall, which are at right angles with the central range, it will be frequently found that the schistose rocks run up there to a considerable distance, forming, as it were, bays and inlets on the sides of the large insulated masses of granite: sometimes, indeed, these intruding beds of slate meet from opposite sides, and thus cut off patches of granite from the main masses. In this manner the Tregonning and Godolphin Hills are separated from the granitic hills of Crowan and Wendron, by the intervention of a narrow valley of slate: and even the hollow, which divides the former hills from each other, appears to be superficially covered with a schistose rock. It has been lately ascertained that the granitic mass of Hingston Down is not continuous at the surface, as laid down in the map, but is also divided into two parts by the slate which ascends very near to the summit even of Kit Hill, the highest part of this range: and one of the projecting granitic hills near Redruth is said to be separated from the main mass by a narrow and shallow band of slate, which passes over the concave curve south of that town.

Thus we learn how difficult it is, even in a country comparatively so well known as Cornwall, to trace the precise boundaries of the rocks, since even the distinctly characterized granite and slate cannot be accurately laid down, unless minutely examined step by step. It is, therefore, very probable that every succeeding enquirer will find the granitic masses of Cornwall more penetrated and intersected by slate than his predecessor. This circumstance, combined with the facts, that the thin and superficial portions of slate are often completely disintegrated, and therefore subject to be obliterated by the next current of water which may pass over them; and that in many primary districts the granite is almost entirely concealed, only appearing here and there in small conical masses, which, in consequence of their greater durability, must increase in extent by the progressive removal of the adjacent decomposing slates resulting from the action of the elements; —all these things tend to indicate that the granitic masses were, at one time, more extensively enveloped in slate than at present; and to render it probable that they were originally entirely surrounded thereby, and that therefore their present protrusion must, in some measure, be attributed to the subsequent decay and removal of the stratified rocks by the operation of causes now in action.

This explanation of the relative position of these rocks is, however, only considered as applicable to the more recent and subordinate changes which have taken place: but this subject will be discussed hereafter; we must, for the present, confine ourselves to a description of the situation of these rocks near their junction.

"The mountain of Lugnaquilla, in the east of Ireland," says

Mr. Weaver*, "rises in bold granitic precipices above Aughavanagh, and is capped with mica-slate, which occupies its summit and a considerable part of its western declivity; while the steep brows around this mountain, its precipitous sides towards Glenmalur on the east, and towards the glen of Imale on the north, and its long southern arm, consist of granite. This cap of mica-slate is also partly interstratified with beds of granite, and these alternations are sometimes traversed by veins of granite. The summit of this mountain forms a kind of table land, presenting a smooth green sod, and is strongly contrasted with many of its neighbours."

This cap of mica-slate appears to be a continuation of the main mass which forms inlets in the adjacent glens: but the picturesque summit of Cadeen consists of a shield-shaped mass of mica-slate, for granite occupies the foot in every direction.†

In tracing the slate near its junction with the granite, in Cornwall, it will be found, in consequence of its undulations, sometimes to rise high on the side of the granite; and again, at a short distance therefrom, to sink to a much lower level, where it lies concealed under several layers of recent deposits, such as alternating beds of gravel, débris, and vegetable remains, which, when tin ore is present, are provincially known by the name of *stream-works*. This undulating line is not only higher and lower, at any one part, according to the convexity or concavity of the curve, but the whole line is found to decline gradually from N. E. to S. W., so that the slate which, in the eastern part of the county, attains to 1000 feet in height, is, at the Scilly Islands, below the present sea level. This statement is, however, only correct as a general view; for, at many intermediate points, between the beginning and termination of this curved line, the slate will be found more elevated than in places which lie more to the north-east; as is also the case as regards the relative altitudes of the highest points of the granitic range which traverses

* Geol. Trans. vol. v. p. 153.

† Idem, p. 160.

Cornwall in the same direction. These facts may appear to be trivial to those persons who have not paid much attention to this subject; but they will be found hereafter to be important, as furnishing some aid in the examination into the nature of these rocks.

In the Alps, and other granitic countries, the primary slates are disposed near the granite, in a similar undulating form; though the curves do not always run in the same direction. In the isle of Arran, for instance, the primary slates encircle the central mass of granite in the form of undulating hills, with the exception of a part on the eastern side, between North Sannox and the hills above Brodick Wood; where the chain of schistose rocks is wanting, and enormous masses of secondary conglomerate may be traced nearly to the base of the precipices of granite.* It has been supposed, that the primary slates are not only absent from the surface, but that the secondary rock rests immediately upon the granite: it may, in part, repose on granite; but analogy would lead us to conclude that it is also deposited on the slate which, probably, is here continued beneath in the form of a hollow curve. And the primary rocks of the central axis of the Eastern Alps appear to be disposed in the same manner; descending in a curved line from the eastern borders of the Tyrol, where they attain the height of more than 12,000 feet, until they are lost beneath the Gratz and Vienna basins: from these, however, they again emerge in the low ridge of Leitha Gebirge, which separates Austria from Hungary; and after again disappearing under the recent deposits, they rise once more in elevated curves near Presburg, and are prolonged into the mountains which range in a north-easterly direction towards the Carpathian chain. The old rocks of the Leitha Gebirge ridge form a true anticlinal axis, from which the tertiary deposits dip in opposite directions; and there can no longer be any doubt of

* Geol. Trans. New Series, vol. iii. p. 22.

the prolongation of the Alpine chain in the direction above indicated.*

Thus we learn that the absence of either the granitic or schistose rocks, or of both, at the surface, does not indicate that they are altogether wanting; for they are frequently found to exist at a lower level, being only concealed by a subsequent and more recent formation. In the Brora district, for example, rocks of the oolitic series are in contact with the granite; and the primary slates might be supposed to be absent, if they had not been detected in small patches at Clyne Kirk and near Loch Brora. It is, therefore, very probable, that the granite is always surrounded by primary slates, as is commonly the case: that the latter are not always visible, may be attributed to the form of their surface, or to an extraordinary accumulation of the newer deposits.

By these remarks, it is by no means intended to advocate a universal order of succession among the rocks; but only to contend that the primary slates do succeed the granitic rocks, when they are not visible at the surface; and that this circumstance can be explained by the analogy of those places where the slate sometimes rises high on the granite, and at other times falls to a low level in an undulating line; thus permitting newer formations to occupy its hollows, and to come into contact with the granite.

The next point for consideration is the angle at which the primary strata are placed when in the vicinity of granite. In Arran, this position of the beds of schist can be determined with certainty in many parts of this junction; and they may in general be said to recline against it: yet if, in some cases, a given bed of schist be prolonged towards the granite, it will be found to indicate the contact of the edges, instead of the faces; while, in tracing the linear direction of the strata in a third set, they will tend to abut endwise

* Geol. Trans. New Series, vol. iii. p. 305. Professor Sedgwick, and Mr. Murchison on the Eastern Alps.

against the mass of granite. No general conclusion can, therefore, be drawn with respect to this connection; since even the slight kind of conformity visible at one point of junction, may not be continued perhaps for ten yards.*

This accords with the position of the slate in Cornwall, near its junction with the granite; as will be seen by the following remarks of Professor Sedgwick† on this subject: —

"At the junctions of the granite with the slate, the latter rock may be generally observed to dip from the mass of the former; yet the inclination and line of bearing of the slate are not found universally to correspond with the surface of the rock on which they rest. Thus, in crossing from Marazion to St. Michael's Mount, the slates suddenly change their dip, and rise towards the granite of the Mount; but though they undoubtedly rest thereon, yet their beds do not reach an inclination of more than 10° or 12°, and consequently appear rather to abut against, than repose upon, the almost perpendicular mass of granite. Again, the slate which commences to the west of Lamorna Cove, has nearly a uniform dip towards the E. and S. E.: and the line of bearing of its strata does not afford any indication of the very uneven surface of the granite on which they rest. The whole mass of slate appears to repose obliquely on the granite, and at its western junction rises into high cliffs, the upper beds of which spread over the fundamental rock, while the lower beds seem to lean against, rather than repose upon, the precipitous face with which they are in contact. At the eastern junction of these rocks, the slate rests on the granite; but in such a position, that their great line of cleavage, if produced, would abut against the headlands of the latter rock."

This disposition is well exemplified at Mousehole, on the same range of coast, where the junction of the granite and slate is exposed for more than a hundred feet in length, running in an undulating line across the direction of the strata;

* Western Islands of Scotland, vol. ii. p. 353.

† Trans. of the Philos. Soc. of Cambridge. On Devon and Cornwall.

the ends of which, however, do not abut against the granite in an abrupt manner, but repose on it in such a manner as to fill all the inequalities of the irregular curvatures of the fundamental rock: so that, at the surface of these rocks, the seams of structure developed by partial disintegration, not only run in the same direction, but traverse both rocks in continuous lines parallel with the bearings or strike of the strata.

The granite of Galloway, according to Sir James Hall, presents similar indications, at its junction with the slate. "In the bed of the river, at the High Bridge of Dee, the granite dips from the centre of the mass at an angle of 45°, and the strata lie upon it in a *conformable* position: but, at the southern extremity of the Hill of Lauren, at Loch Ken, the character of the junction is very different; the strata here are nearly vertical, stretching from north to south. The line of junction which occurs on the face of the hill towards its summit, cuts the strata at various angles, sometimes nearly at right angles; and the strata thus abutting endwise against the granite, the two substances are, as it were, spliced into each other." *

Other examples might be quoted on this subject, but the fact that the granite and slate meet under such different aspects, is well established: and, indeed, it follows, from the curved outline and projecting masses of the former rock, which run into the slate after the same manner, as the land into the sea, that the strata having a regular *strike* or bearing must sometimes abut against the granite. But, notwithstanding this apparent irregularity of position in these rocks at their junction, there is in reality no want of order; a careful and minute inspection will remove the appearance of confusion which seems, on a cursory view, to prevail; and the clue by which this labyrinth may be unravelled, is the structure of these rocks, or that arrangement by which their con-

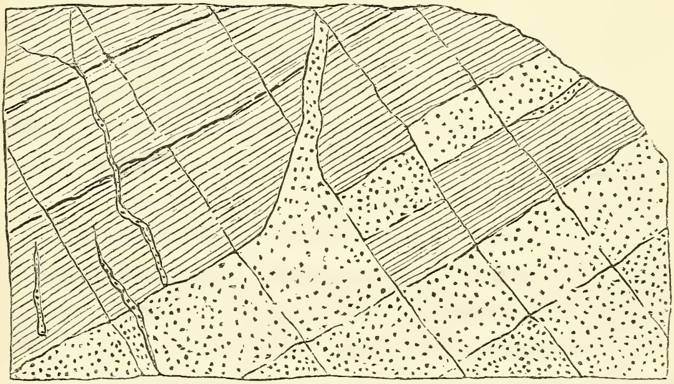
* Royal Transactions of Edinburgh, vol. vii. p. 99.

cretions are aggregated together: a subject which has not as yet sufficiently occupied the attention of the geologist.

In the last chapter, we gave a sketch of the structure of the granite and of the slate; we now propose to offer a few examples of the structure of these rocks at their junction, which occur in the Land's End district, where the union of these rocks is so instructively displayed.

Thus, in the first place, at Polmear Cove, on the north coast, the slate reposes on the granite at an angle of about 45°; and these rocks, at their junction, not only form parts of the same concretions, but also of the same beds; the under part consisting of granite, the upper of slate, owing to both rocks possessing the same rhomboidal structure; as may be seen in the annexed diagram.

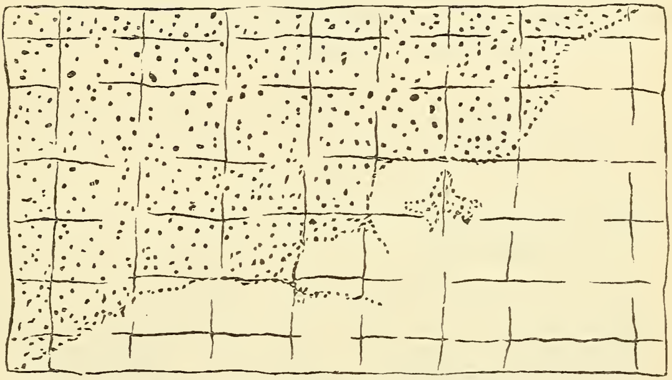
Fig. 6.



Junction of Granite and Slate at Polmear Cove, Cornwall.
(Cliff Section.)

In this place, the beds of granite are often separated from each other by thin parallel layers, or veins, of shorl-rock; so that the beds are more distinctly developed, in the direction of the greater angle, whilst the laminæ of the slate follow the lesser: these beds also decline in the direction of their strike towards the sea, and along this slope the waves are gradually removing the slate. At St. Michael's Mount, and at Mousehole, the slate rests on the granite at a less angle; otherwise the appearance is the same as that of Polmear, though not so distinctly displayed. At Mousehole, the slate thus situated only occurs in thin portions, apparently the residue of the under surface of a mass of slate which once existed: the slate, here, for the most part meets the granite endwise, and is exposed in a horizontal section; so that, following the beds of granite along their course, we enter on the beds of slate, which appear to be a continuation of each other, thus:—

Fig. 7.

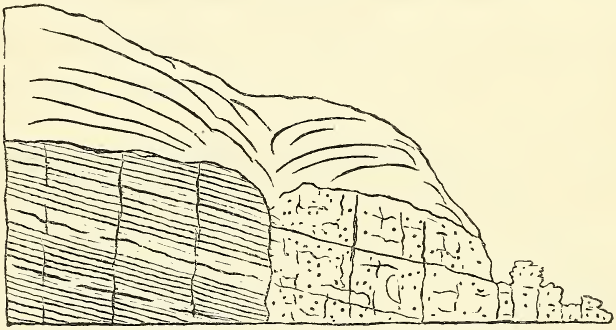


Junction of Granite and Slate at Mousehole.
(Ground Plan.)

Along the line of junction, which is much undulated, slate sometimes constitutes a portion of a granitic block or concretion; and at others, the reverse holds good: that is, the line of structure is often coincident with the line of junction, but is sometimes indifferent thereto, separating a portion of slate or granite as the case may be; and, when this happens, the one rock cannot be detached from the other; as they form a compact and individual concretion. At Mousehole, the nature of the union in perpendicular sections may be detected on a small scale, at many points, owing to the rocks having been irregularly abraded by the waves.

On the eastern side of Rosemodris Point, the slate is not only seen reposing on the granite, at a considerable angle in the upper part of the cliff, but the beds of both rocks meet each other endwise as at Mousehole; but with this difference, that the line of union is nearly perpendicular, corresponding with the parallel fissures in the granite, which are clearly seen to owe their position to one system of planes of the rhomboidal concretions being placed upright. The other two planes dip at different angles, and the *strike* of these beds declines towards the nearest granitic headland; so that in tracing the lines of structure through both rocks, they seem to form the continuation of the same beds; the eastern ends being of granite, the western of slate.

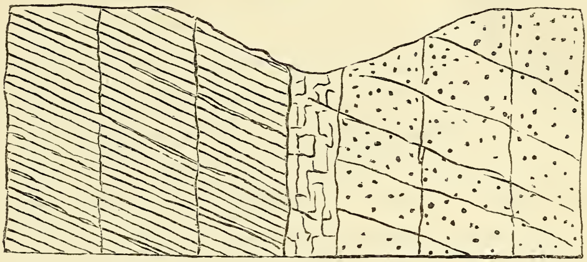
Fig. 8.



Junction of Granite and Slate at Rosemodris.
(Cliff Section.)

The junction at Porth Just, near Cape Cornwall, is similarly circumstanced, though the appearance is more complicated by the occurrence of a large metalliferous vein which is situated precisely between the granite and the slate. This vein, in the perpendicular section of the cliff, appears to form, as it were, the end of a regular bed of rock corresponding with the beds of the granite and slate on either side; but the lines of concretion are not regularly continued through the vein: some slight indications of such a disposition are visible at several points; and that they are not more distinct, may be attributed to the very compact and comparatively indecomposable nature of this quartzose vein. The structure and composition of this vein and the adjacent rocks will be considered more in detail in another chapter: at present the relation of the granite and slate may be seen in the following figure: —

Fig. 9.



Junction of Granite and Slate at Cape Cornwall.
(Cliff Section.)

In several spots, at the places now referred to, the lines of structure are distinctly and regularly continued through both the granite and the slate; but it must be also understood, that in adjacent spots this continuation cannot be seen, the corresponding lines not being in the same direction, or altogether wanting in one of the rocks: it is, however, to be borne in mind, that the individual beds of both the granite and the slate exhibit precisely the same appearances.

This disposition of the primary slates at their junction with the granite appears to indicate that the latter was, at one time, completely enveloped at the surface by the former. Be this, however, as it may, we now find the granite, at various points, protruding through the slates, and generally occupying the most elevated positions. These masses sometimes are arranged in nearly circular forms of various extent, from several leagues to a few hundred feet in diameter; at other times they are elongated into considerable ridges, forming what has been termed anticlinal axes, on account of the strata dipping from them on either side, like the roof of a house. The Ocrynian ridge, extending from Dartmoor to the Land's End, has been regarded as such an anticlinal axis: in a general point of view this is correct, but when each of the insulated masses of granite are examined, they will be found more or less concentrically enveloped by the adjacent slate; and not only so, but, if lines be drawn through their centres, parallel with the general strike of strata, N. E. and S. W., it will be perceived that there are several lines or axes many miles remote from each other. Whether this condition of the Ocrynian ridge accords with all mountain-chains, the granite of which is subject to like arrangements, we are not prepared to answer: but this we know, that the Cornish range is not a solitary example: — " La recherche d'un axe granitique," says M. Reboul, " me paraît, jusqu'à ce jour, avoir été infructueuse. Les masses de cette roche forment au sein des Pyrénées comme de grandes îles qui ne s'éloignent, ni entre elles, ni avec l'axe géographique." " Ainsi, la chaîne des Pyrénées, quoiqu'elle soit l'une des plus simples, est néanmoins composée de plusieurs arêtes qui affectent des directions différentes, soit dans l'alignement de leurs masses, soit dans celui de leurs strates: — et cette disposition l'assimile aux autres chaînes plus compliquées." *

Having considered the relative position of the granitic and schistose rocks, it is now proposed to examine the composition and nature of these rocks at their junction; and, as might be expected, Cornwall also affords excellent opportunities for this investigation.

It has been already stated, in the description of the schistose rocks, that those which immediately succeed the granite, differ in their composition from those that are more remote; and so it likewise happens, that the beds of slate adjacent to the granite generally assume a different aspect as they come into actual contact with this rock. Thus, the slate of the eastern district (proteolite) becomes more granular and micaceous as it approaches the granite; and the slate of the western district (cornubianite) loses the fine-grained and compact texture, so characteristic of this felspathic rock, acquires a granular texture, and at the same time the accessory mineral, whether mica, shorl, or hornblende, is developed into distinct scales or crystalline granules, imparting to the

* Bulletin de la Soc. Géol. de France, tome ii. p. 79.

slate appearances which have been likened to some varieties of gneiss: and it is no uncommon occurrence, in all these cases, for the compact felspar base, by the gradual increase of its silica, to become more and more quartzose; the beds of these slates next the granite being hard and brittle, exhibiting a sharp and splintery fracture, and very little tendency to separate into laminæ. Particular references for each of these appearances need not be given, for the same bed, even within very narrow limits, assumes various aspects: indeed, even in the same concretions, the slate may in one part be quartzose, in another micaceous, resembling gneiss, and in a third (but often in adjoining concretions) the texture may be fine and uniform, and as fissile as the slate at a mile distant from the granite. These facts are well illustrated in the extensive horizontal section at Mousehole, and may, in a lesser or greater degree, be observed at all the junctions on the coast of the Land's End district: so that, although there is no determinate order in the arrangement of the varieties which each kind of slate presents when in immediate contact with the granite, yet it is established that the slate, in such a position, always partakes of different characters, arising from alterations in its composition and texture.

The granitic rocks, also, as they approach the junction, are likewise subject to similar transitions from the most perfect form to a state which, if viewed apart from the main mass, would sometimes not be easily recognised as granite. The most common mode of this metamorphosis is effected by the basis of a porphyritic granite becoming gradually very fine-grained, and alternating with layers of the same, in which the crystals of felspar are wanting. When the basis is very fine-grained, it perfectly resembles the compact felspar of *elvan-courses;* and when, in this state, it comes in contact with granular slate, they can only be distinguished from each other by the dark colour of the latter, and cannot be perfectly separated by the hammer: sometimes, however, they are distinctly divided by a seam or joint, each rock being confined to distinct concretions; and this more generally obtains when the granite abounds in crystals of felspar at the junction: but even this does not constantly hold good; for sometimes these prophyritic crystals, as at Polmear Cove, are also contained in the dark-coloured slate, for many inches from the point of contact of the two rocks, and this intimate union is farther displayed by this phenomenon occurring in the same individual block or concretion. Oftentimes the granite is very quartzose at its junction, and gradually passes into quartzose varieties of slate; or, as at Porth Just, Cape Cornwall, this transition takes place through the medium of a large quartz-vein (Little Bound's Lode), into which the granite and the slate, on either hand, distinctly graduate. In short, the granite and slate of Cornwall, at their junction, are frequently so similar, both in composition and concretionary structure, that the detached blocks, as they lie side by side, cannot at a little distance be distinguished from each other; the darker colour of the slate, and its tendency, often slight, to break into laminæ, are sometimes the only differences to be detected on a closer inspection.

We will now examine whether the junctions of other countries afford similar facts. M. de Caumont, in his account of the department of Manche, in France, has detailed the appearances of the passage of slate into granite. Near Cherbourg, a greenish schist contains fine particles of felspar, which gradually become more and more abundant; at the same time grains of quartz become visible, and the rock assumes a granular texture: and, in these places, it resembles a kind of gneiss or talc-schist, or, rather, the nodular steaschist of Brongniart. At last, the grains of felspar and quartz, elongated and imbedded between the laminæ of the schist, gradually lose this regular arrangement, acquire a more crystalline form, till the mass becomes a granite or syenite.*

The junction of the granite and mica-slate is thus described

* Bulletin de la Soc. Géol. de France, tome iii. p. 11.

by Mr. Weaver, in his account of the east of Ireland:—"In a ravine, which marks the northern face of Crogan Moira, we may observe that the granite acquires more and more of a quartzy nature as it approaches the mica-slate, becoming almost slaty-quartz at the point of contact; while the mica slate itself abounds in beds of quartz of variable thickness, and the granite is traversed in all directions by contemporaneous veins of quartz of greater or less magnitude, and also by veins of granite." *

In the Island of Iona, according to Dr. Macculloch, a few rocks of red large-grained granite occur on the shore below the Bay of Martyrs, and are in contact with the schist. The latter rock, at a distance from the granite, is described as a black compact clay-slate, occasionally containing hornblende, and sometimes mica, and seems to hold an intermediate place between clay-slate and gneiss: but when in contact with the granite, it puts on a remarkable appearance, displaying externally a singular mixture of black and red. It is very hard, and its fragments are as sharp-edged as siliceous flint. In many places this schist loses its black colour and becomes grey; in others it is mottled with red felspar, and interspersed with quartz, which minerals increasing in quantity, the slate appears to be on the very verge of passing into the granite with which it is nearly in contact, the sea, in this place, preventing the actual contact from being examined; else it is probable that a still more perfect series of this transition might be observed. The junction of argillaceous schist with granite is not rare in Scotland; but this is the only instance seen by Dr. Macculloch, in which the interference of the latter is of such a nature as to produce the appearance of a real transition from the one to the other rock.†

In the Island of Mull, says the same author‡, a long and interesting line of the junction of granite and the primary

* Geol. Trans., vol. v. p. 152. † Western Islands of Scotland, vol. v. p. 15.
‡ Idem, vol. i. p. 554. *et seq.*

strata can be traced at Loch Laigh, the shore fortunately lying in a direction oblique to the line of junction. It presents a very distinct view of appearances of considerable value towards the history of granite, which, however frequent in the mainland of Scotland, are nowhere to be seen under more favourable circumstances. There are two kinds of granite in Mull, the one of a pale flesh colour, and the other of a high red: these rocks are large-grained, yet compact, and their mica is black. The strata consist of an alternation of micaceous schist and quartz-rock; and in some places the former puts on the characters of a schistose gneiss. When these rocks come in contact with the granite, they assume the following appearances:—The quartz-rock becomes red, and is found to contain felspar in large proportion, often resembling fine-grained gneiss; and it thus frequently passes into granite by a transition nearly imperceptible. The mica-slate, in the same situation, becomes a true gneiss. These changes, however, are very partial, commonly confined within a few feet of the junction, and gradually vanishing as they recede. At a distance from the granite the strata are thin and regular, but next this rock they are variously disposed: in some places they continue in the same direction, and in others their ends, or even their sides, are united to the granite, and so firmly adherent, that they cannot be separated; and this irregularity is greatest where veins pass from the granite into the strata. It is worthy of remark, that the junction sometimes takes place between the granite and the mica-slate; at other times, between the former and the quartz-rock. This is an important circumstance, since these beds being parallel, the granite is not parallel to them; being found in contact sometimes with one, and sometimes with the other, stratum.

Here, also, as frequently happens at the junction of these rocks, fragments of the strata are detached from the main body and imbedded in the granite: and in some cases these are so distinct, that the parts whence they were separated may be traced, and the fragments, in imagination, re-united.

Such is the nature of the junction of granite with the primary slates. Many of the appearances which it presents might be expected, when it is remembered that these slates do not differ much in composition from the granite; and it therefore becomes an interesting enquiry what would be the result if granite were thus to be united with a stratified rock of a different nature. This desideratum is, indeed, already supplied by the exhibition, in several countries, of the interference of granite with calcareous rocks.

The junction of granite and limestone is beautifully exhibited at Glen Tilt, in Scotland, and has been carefully examined and minutely described by Dr. Macculloch: indeed, his whole account of Glen Tilt * is so very interesting, and so replete with excellent details, showing the nature of the stratified rocks, both at a distance from, and in immediate contact with, the granite, that we propose to make some lengthened extracts.

The granite which forms the right ridge of Glen Tilt appears to be a continuation of the great central granite of the Grampians, constituting its termination in a southern direction. The varieties of this granite are mixtures of quartz, felspar, and mica; differing, however, as much in colour and texture as they do in structure. To these minerals hornblende is often added, sometimes to the exclusion of the mica. These syenitic granites are almost invariably grey, or even black, from the predominance of the hornblende: their texture is as various as their colour, the crystals of hornblende being sometimes very large, and imbedded, as it were, in a paste of quartz and felspar; while in other extreme cases the mixture of the several ingredients is so fine, that the constituents can scarcely be discerned; and it is only to be distinguished from greenstones of the trap family by tracing it for some space until it passes into well-characterised granite. The chief varieties of syenitic granite are found on the slopes which

* Geol. Trans., vol. iii. p. 259. *et seq.*

descend to the junction, with the schistose rocks, in the vicinity of the Tilt. In this place, as in many others, the different kinds of granite are found together, not forming veins nor distinct masses, but graduating into each other by an indistinct transition. The granite, at its junction with the schistose rocks, consists chiefly of red felspar and white quartz, of which the latter is generally in the smallest proportion, the compound mass containing obscure crystals of dark green hornblende. These are seldom in large quantity; more commonly they are thinly dispersed through the rock, and not seldom, even in the largest masses of rock, they are altogether absent. Mica has not been observed in the granite at its junction with the slate.

Amongst the stratified rocks, limestone is the most extensive and the most characteristic of this district.

The great mass of the limestone, which forms nearly the whole of the left boundary of Glen Tilt, is of a lead blue colour of various intensity, and its texture is almost universally large-grained and highly crystalline: here and there, however, it presents some beds of the most beautiful ornamental marbles which Scotland has yet produced. These marbles are seldom pure, at least to such an extent as to be adapted for the purpose of statuary, but are combined in various proportions with a great variety of minerals. Mica is more frequently present than any other substance, and, near the junction of the Tilt with the Garry, this mineral is so abundant, that the rock may be easily mistaken for micaceous schist: it has a foliated structure, owing to the mica and calcareous matter being disposed in alternating laminæ, the latter rarely exceeding the twentieth of an inch in thickness. Besides mica, this limestone is mixed with steatite, serpentine, talc, asbestus, tremolite, and various other minerals, which are disposed in the form of veins or patches; or, by their intimate union with the limestone, produce mottled, clouded, and otherwise variegated marbles.

Such is the nature of the limestone at a distance from the granite, where it forms a continuous bed over a very large tract of country, with an elevation somewhat varying, and, consequently, in an undulating plane: its dip is invariably to the south, at an angle of from 5° to 50°, and even to 60°. In one place, a considerable contortion of the bed occurs, and in many others, fractures and dislocations of it may be seen. "Yet, with such partial irregularity," observes Dr. Macculloch, "we may still safely consider the general parallelism and stratification as regular, and the dip as a medium constant quantity of, perhaps, twenty degrees." But when the limestone is contiguous to the granite, it assumes, with some few exceptions, a very different aspect. Its large-grained and crystalline texture disappears, and it more nearly resembles hornstone or compact felspar, having a smooth texture, with a thin-edged fracture intermediate between the splintery and flat conchoidal: it is very hard, effervesces slowly with acids, and gives on analysis a large portion of siliceous matter; and its external aspect, where it has been worn by the action of the river, is not much unlike that of granite or porphyry. In every instance, all particular or minute regularity disappears, wherever the limestone beds are found in the immediate vicinity of the granite: they are generally much contorted, and so intermingled and blended with the accompanying strata, and with the granite, that the whole mass appears to be in a state of utter confusion.

The other strata, which accompany and alternate with the limestone, are schist and quartz-rock,—terms which have also such an extensive signification, that it is absolutely necessary to describe them at length.

The schist of Glen Tilt rarely maintains the same character for any considerable space: the most abundant is a clay-slate, rarely fissile, and generally of a very compact texture, and dark blackish-blue colour. It sometimes possesses a glossy and unctuous surface, and passes into a kind of talcaceous schist. It is often much penetrated with quartz, and sometimes finely interlaminated with the same substance:

at other times it is intermixed with hornblende, and passes into hornblende schist: this occurrence is frequent at the junction with granite, where also the schist, when merely argillaceous, generally displays unusual hardness. Micaceous schist also occurs, and, in general, it is characterised by the predominance of the quartzose ingredient; and in this way it passes into quartz-rock by insensible gradations. The disposition of the strata of schist is the same as that of the limestone; and when these two rocks alternate together, the limestone is often interfoliated with thin laminæ of the schist, in consequence of which they appear to graduate into each other. These two rocks are not always regularly parallel with each other. "Near Gow's Bridge, a white marble is surmounted by a bed of hornblende schist; this is followed by marble about two feet in thickness, of which the greater part is suddenly cut off at right angles to the bed by a second mass of hornblende schist; while the lower part continues in the same direction, but bent, and of the breadth of only two or three inches. The lower part of the mass of schist, which thus intersects the marble, is also protracted in a thin plane, continuous with the thin part of the marble, and lying above it; while the upper side of the same becomes continuous with a regular and thick bed of the schist. A thick bed of marble is therefore included on three sides within the hornblende schist, its outer extremity being cut through at right angles by the schist. As the beds dip into the hill, the further progress of this arrangement cannot be traced."

The quartz-rock of the Tilt is similar to that generally associated in Scotland with gneiss and mica-slate in the vicinity of the granite. It is frequently of a bluish colour, very uniform and compact, and approaching nearly to common quartz in character, but still showing evident marks of foliation. When it approaches the limestone and schist, with which it alternates, all these rocks are found to pass gradually into each other.

This quartz-rock, however, very frequently contains felspar;

and, when this is the case, its beds sometimes exhibit all the constituents of granite, so disposed as to resemble the foliated texture of gneiss, and, in some instances, a perfect granite; and, when this is the case, this quartz rock is followed by a schist, which seems intermediate between gneiss and mica-slate, having the aspect of the latter with its shining surface, and even foliated structure, but showing in its cross fracture the grains of felspar which belong to the former. This granitic variety of quartz-rock occurs at a considerable distance from the mass of granite, and the schistose beds are straight and undisturbed.

Such is the nature of the granite and the adjacent schistose rocks at Glen Tilt; and, before proceeding to point out their analogy to the primary formation of Cornwall, there are some phenomena exhibited by these rocks which require to be noticed.

It has been already remarked, that, at a distance from the granite, the alternations between the limestone, schist, and quartz-rock are regular and well-defined: but when the granite is approached, the lines of stratification become irregular, and the dip of the strata is in almost every direction; and immediately adjoining the granite there is a general mixture of all the stratified rocks, and a total discomposure of their regularity, which is increased by the presence of elongated and detached portions of the granite. It is worthy of remark, that at the junction the strata are not continuously in contact with the granite: on the contrary, it is sometimes the schist, sometimes the quartz-rock, sometimes the limestone, or there is a want of conformity between the granite and the rocks which lie above it.

The granite and the strata in the bed of the Tilt have frequently the appearance of alternating together; but all the circumstances are nowhere so clearly exposed to view as to warrant a positive conclusion. Dr. Macculloch is of opinion, that "those parts of the granite which seem to alternate with these strata can only be considered as portions of veins, the disposition of which, like that of trap veins in similar cases, has accidentally coincided with the direction of the beds."

Hornstone and felspar porphyries frequently occur in the course of the Tilt on both sides of the valley. These sometimes appear to be veins, and at other times assume the form of beds: but it is difficult to ascertain their true nature. When the porphyry is parallel with the strata, resembling a bed, it has oftentimes the appearance of alternating with the schist, quartz-rock, and limestone.

The excellent and circumstantial description of the junction of granite and the limestone series in Glen Tilt has led us to make longer extracts than was anticipated; but the importance of the subject required that the nature of this connection should be fully and clearly detailed. Examples of a similar description are of frequent occurrence in the Alps and Pyrenees; with this difference, that the fossiliferous strata with which the limestone is connected are of a more recent formation. In these countries, however, we cannot obtain such distinct and minute displays of these rocks at their actual contact; but, on the other hand, the limestone of these mountainous regions, which are crystalline, and immediately associated with the granite, are often of less extent, and, consequently, the secondary strata, into which they appear to pass, are not far removed from the granite. These phenomena furnish some of the most important evidences in favour of the plutonic theory, and, therefore, it is necessary to subjoin to these lengthened details at least one example from the eastern side of the Pyrenees, as described by Dufrenoy.

" Near Saint Paul de Fenouillet the limestone is associated with a black marl enclosing fossils which belong to the inferior beds of chalk, and are disseminated in the form of black casts imbedded in a bluish-grey crystalline limestone: these remains are not easily detected, unless a great number of them have been examined; for they appear to have been so compressed, and adhere so strongly to the limestone, that it is difficult to separate even characteristic fragments. From the bridge over the Fou, to a place where the Gly enters into a narrow and deep gorge opened in the nearly vertical beds of crystalline limestone, the characters of the latter rock are such as have been described; but here, at the distance of about a thousand feet from the granite, the limestone is perfectly saccharoid, and does not contain a trace of organic remains. Here the following disposition of the rocks may be observed. The strata dip towards the E. 25° S., at an angle of 75°, appearing to repose on the granite which forms the hills of St. Martin. This crystalline limestone continues to within about a hundred yards of the main mass of granite, and, indeed, within a hundred feet of a branch of this rock, which will be presently described. Then succeeds, —

1. A reddish ferruginous limestone, about fifty feet in thickness, and disposed in beds regularly stratified. It is worthy of remark, that no passage can be observed between this rock and the grey limestone by which it is covered. The line which separates them is well defined; which is not the case with the rock immediately subjacent.

2. Beneath the red limestone, is a dolomite, which is very solid, although composed of small distinct rhomboids aggregated together. This rock is more than fifty feet in thickness, and is not stratified. It decomposes in a very irregular manner: its surface is deeply coloured, although in a fresh fracture it is of a light yellowish tint. It contains some very irregular veins of spathose iron ore.

3. The dolomite rests on a very quartzose felspar rock, which forms a kind of venous bed, or *floor*, about sixty-five feet in thickness. It is difficult to convey an exact idea of this rock: it seems to have been produced by the penetration of the granite into these strata, and is, consequently, a mixture of very different elements. This mass is in nowise stratified. It contains spathose iron ore, pyrites, and a little iron glance.

4. The compound of dolomite and spathose iron ore, already described as superimposed on the quartzose felspar rock, again occurs beneath the latter, in a layer about two yards thick; and this, again, rests on, —

5. A granitic rock, unstratified; forming, nevertheless, a mass disposed in parallel beds, the thickness of which exceeds a hundred feet. This rock consists of large-grained felspar, green mica, and a very small proportion of quartz: it is intermixed with the above mentioned ores of iron, in small groups, or nests; and in the vicinity of these minerals, the rock appears to be altered.

6. This granitic rock is again succeeded by dolomite; which is about twelve yards in thickness, and is not so regular as the two preceding beds above described: its surface is not even; for the dolomite penetrates a little into the granitic rock, and also into the granite on which it reposes. It still contains spathose iron ore, but is particularly rich in various kinds of iron glance.

7. Lastly, we arrive at the granite which constitutes the hills of St. Martin. It differs essentially from the rock 5, being fine-grained with black mica: but, notwithstanding this difference, we may rest assured that the granite rock contained in the dolomite is a ramification from the granite.*

The description of the junction of granite and limestone, in this interesting locality, is somewhat blended with conjecture, and does not furnish such minute details as Glen Tilt, owing, probably, to the sections being less favourable for observation. We shall revert to this example when we examine the nature of the evidence on which it has been concluded that this granite must be of more recent origin than limestone.

Such is the condition of various primary strata at their junctions with the granitic rocks; and though they do not all exhibit precisely the same appearances as those of Cornwall, yet the points of resemblance are sufficiently numerous to render it probable that the phenomena are of the same nature, being only somewhat modified by local circumstances.

* Bulletin de la Soc. Géol. de France, tome ii. p. 71.

CHAPTER VIII.

ON THE VARIOUS MODES IN WHICH THE GRANITIC AND SCHISTOSE ROCKS ARE ASSOCIATED TOGETHER.

The occurrence of granitic rocks in the primary schists — in the form of beds or courses — in irregular bunches or masses — in Cornwall, — Scotland, — Ireland, — and Norway. — Portions of these schists also contained in granite — in Cornwall, — in various parts of Scotland, — and in France. — The primary strata traversed by granite-veins — in Cornwall — and in Scotland. — Summary of the various appearances presented by these veins.

Having detailed in the preceding chapter the nature and position of the schistose rocks at their point of contact with granite, it is now proposed to consider how these stratified and unstratified rocks comport themselves, when more intimately intermixed in the form of beds, dykes, veins, and detached portions of various irregular shapes and dimensions.

Some of these circumstances have been necessarily anticipated, more or less, in the foregoing descriptions; more especially the occurrence of large and regular masses of granitic rocks in the primary slates, as those of Cornwall, and analogous examples in other countries, of which those of Ireland, recorded by Mr. Weaver, are most minutely described. These granitic beds, commonly known in Cornwall by the name of *elvan-courses*, are sometimes so numerous, and so regularly placed in the slate, that they appear to alternate therewith; and, indeed, this mode of association is more regular and persistent than is often to be met with among the different kinds of primary slates; for these pass into each other, at various points, through such frequent and almost imperceptible gradations, that the same order cannot be detected. These *elvan-courses*, however, also exhibit great irregularities, if we descend from the general outline to a minute examination of their junction with the containing schists: they, in fact, display all the phenomena which occur at the junction of the main masses of granite and slate. Thus, the elvans often protrude or bulge out in the form of angular or rounded protuberances, which sometimes appear to be separated from the *course* by open seams, which run parallel with the regular part of the elvan, and continue uninterruptedly in the same line; so that if the projecting portion be small, it will often be found to form a part of the adjacent schistose concretion; they, likewise, are sometimes elongated into lateral branches, or terminate in minute strings, after the manner of veins; and it is no uncommon occurrence for insulated pieces of the elvan to be imbedded in the slate, and, *vice versâ*, for those of the latter rock to be contained in the former.

For farther particulars concerning the situation of these granitic beds in the slates, we must refer to the fourth and fifth chapters: those details ought to have been given in the present chapter, but by so doing we should have separated from them one of the most characteristic features of the schistose rocks, and thereby rendered the description very imperfect.

Besides these somewhat regular beds or courses of granitic rocks, irregular masses or bunches of various dimensions also occur in the primary slates. These are particularly abundant near the junction, as is well illustrated on the sea-shore near the village of Mousehole, in Cornwall; where they are seen to be connected with the slate on all sides, sending out veins, passing into the slate by mineral gradations, forming, with portions of the slate, the same concretions, and also containing insulated pieces of slate of different sizes and shapes. It might be contended that these bunches of granite are merely protuberances of the subjacent granite: in some cases, even at Mousehole, they probably are; but that they are not always so, is demonstrated by the workings of Dolcoath mine, where several of these outlying masses of granite have been found to be perfectly insulated.

That these appearances have not been more commonly observed, may be attributed to the want of favourable sections, and not to the primary rocks of other countries being differently constituted: an example of this nature has, indeed, been recorded by Mr. Weaver, as occurring in the eastern part of Ireland. "The brow of Tonelagee," he says, "exhibits bold precipices from four to five hundred feet in height. The northern and southern portions of this are composed of granite; but, in the interval, there is a body of mica-slate about two hundred yards wide, including a bed of granite which varies from six to ten yards in width, besides irregularly formed masses of the same rock imbedded in and incorporated with the mica-slate. It appears to be a prolongation of the body of mica-slate at the head of Glenmacanas, gradually narrowed in its western progress, and probably tapering to an edge, so as to constitute a kind of wedge-shaped mass inserted in the body of the granite."*

If any doubt should still remain as to the occurrence of granitic rocks as insulated masses in slate, it may be stated, that this does actually take place in the Herland mines, which are more than a mile distant from the nearest body of granite. Indeed, the irregular veins and bunches of granite in the gneiss of Scotland and Norway are of the same nature: they have been sometimes called granitic gneiss, and have been attributed by others to an injection of granite; but let their origin be what it may, they are evidently analogous to the insulated portions of the granitic rocks in the slate of Cornwall. Refer to the examples quoted in the fifth chapter, and more particularly to Macculloch's description of the Western Islands of Scotland, where "lumps of granite, apparently independent of veins, are often imbedded in the gneiss; and when they are large, commonly give out branches or veins, which diverge in a very capricious manner."

The granitic rocks are thus disseminated throughout the

* Geol. Trans., vol. v. p. 145.

crystalline schist, under various circumstances, and in different forms; so likewise the latter rocks occur in detached portions in the granite, not only at the junction, but in the main mass some distance therefrom.

Examples of this kind in Cornwall are on a very small scale, and of rather an obscure nature: at the junction, indeed, portions of slate are entangled with, or even enveloped in, the granite; but even in this position they are not always very distinct, owing to the slate being of a compact and crystalline character, not readily distinguishable from the granite, when this rock has not its ordinary appearance. In every portion, however, of the granitic mass, small concretions may be observed, which have a dark colour and compact texture, owing, apparently, to the constituents of the granite being, at such points, very fine-grained, and intimately united with black mica, shorl, pinite, or other minerals, which are more abundant than in the general mass, attracted as it were round certain centres. But these appearances are better displayed in some other countries.

In various parts of Galloway, Sir James Hall observed portions of slate in the granite at the junction of these rocks: at the Hill of Lauren, "the granite actually contains a mass of the stratified body included in its substance;" and "in the island upon which the Castle of Doon stands, angular fragments of killas are surrounded on all sides with granite."* And on the shores of Loch Doon, Dr. Grierson observed fragments of compact gneiss in the granite, which is here a common and prominent feature, but of more rare occurrence in the Dee district:—"one of these fragments, of a tabular shape, was two feet long, about ten inches broad, and four in thickness. Some of them have disintegrated more rapidly than the granite, and so have left hollows in it, and have, indeed, fallen out: others have weathered more slowly than the surrounding granite, and are seen projecting from the

* Royal Trans. of Edinburgh, vol. vii. p. 102.

surface. These fragments and the granite do not pass into each other, unless the manner in which they unite be called a transition; they are perfectly distinct, but as intimately united as the alburnum of a tree with its wood: the termination of the one, and the beginning of the other, are seen distinctly, but the mass is equally strong at the junction as any where else."*

In the mountains called Ben na vear, near Balahulish, the schist which is traversed by the granite is often much indurated, and approaches by various undefinable gradations to a sort of hornblende-slate. Masses of a similar substance may be found imbedded in the granite. Occasionally these masses appear, on close examination, to be only irregular spots of hornblende, such as occur not unfrequently in those granites of which this mineral forms an ingredient. More often, however, their shape is perfectly defined, being laminæ with truncated edges: and in some places, this appearance of fracture is so precise, that when two fragments occur together in the granite, the imagination as easily replaces the separated parts, as it does in the brecciated marbles or agates: nay, farther, the fragments will be sometimes found to consist of an argillaceous or slightly micaceous schist, maintaining this character with scarcely a perceptible alteration, and sometimes only approaching to hornblende-schist at its exterior parts. It is also worthy of remark, that these fragments sometimes exhibit, at their edges, stripes of different colours and degrees of hardness, arising from the varying texture of the laminæ which compose them. These masses vary in size from an inch to a foot and upwards; but, whatever their size may be, they have almost invariably parallel sides.

At Loch Rannoch, the schist, which is imbedded in the granite, is often composed of black shining mica. Towards the junction of the fragment with the surrounding rock, it generally contains crystals of hornblende. The fragments

* Wernerian Trans., vol. ii. p. 384.

vary much in size; and differ completely in aspect from those accumulated plates of mica, which are found in the granite of Aberdeen, as well as in many other granites. In other cases, the imbedded fragments consist of the same quartz-rock and gneiss which form the general body of these schistose rocks. The head of Loch Spey, a tract far removed, yet possibly not unconnected with this, is also composed of granite; and among this are found perfect granitic conglomerates, in which fragments of mica-schist, equalling in quantity the substance which connects them, are seen imbedded in a paste of granite. Occasionally these fragments are confounded with the granite at their edges; but at times are so defined, and even so separable, that I procured a specimen with a distinct vacant impression of a rectangular fragment, which had probably been detached; as cavities left in this way, by the wearing out of the schist, occur frequently in the rocks of the moor of Rannoch. *

Although the schistose rocks are seen only at the two ends of this prolonged tract of granite, the imbedded fragments can be traced throughout the whole. Dr. Macculloch adds, "that if any one be unwilling to consider these imbedded portions of schist as fragments, it can only be said, that if they were really detached fragments, they could possess no other aspect than that which they now have."

In short, the occurrence of angular and rounded portions of schistose rocks in granite has been observed in almost every primary country, exhibiting various appearances, according to their size and the proportion which they bear to that of the containing mass. "The granite of Braemar, of Aberdeen, and of other districts n Scotland," says Professor Jameson, contains portions of gneiss, mica-slate, clay-slate, and also of porphyry, syenite, and trap, varying in size from a few inches to many fathoms. These masses are to be seen passing by imperceptible shades into the bounding granite; thus showing

* Geol. Trans., vol. iv. p. 126. *et seq.*

that they are of cotemporaneous formation with it, and are not fragments, as has been frequently maintained.* Schistose rocks also occur in a more regular and extended form in granite: thus, quartz-rock traverses the granite of Glen Tilt, as recorded by Macculloch, being of the same nature as that among the adjacent strata; and "the granite of Clis and Pouliguen, in Brittany, contains thin layers or bands of schist which is very micaceous, or rather of mica in mass."†

Of all the modes, however, in which the granitic and schistose rocks are associated together, the most curious, and the most interesting in a theoretical point of view, is that of granite-veins, traversing the slate at the junction of these rocks; and there is, perhaps, no part of the world, where these phenomena are better or more numerously displayed than in the western part of Cornwall. We shall, therefore, select a few examples from those which have already been placed on record.

"At Porth Just, near Cape Cornwall, and below the tin-mine called *The Little Bounds*, the number of the granite-veins," says Dr. Davy, "is considerable; they were not counted, but probably exceed fifty: their size also greatly varies; the largest vein being five feet thick, and the smallest not more than one tenth of an inch. They run in different directions; some about W. N. W. and E. S. E., some about E. and W., and some nearly opposite, as N. and S., and consequently they occasionally intersect each other. In one instance of intersection, the disjointed parts of the vein, running about N. and S., were heaved about half an inch out of the course of the vein. The position of most of these veins is perpendicular, or nearly so: in some places they approach more or less the horizontal line. In composition, they differ very much: some resembling the most perfect granite; others abounding in quartz, and have very much the appearance of

* Annals of Philosophy, vol. iv. p. 419.

† Annales des Mines, tome iv. p. 25.

a fine, compact, granular, siliceous sandstone,—of this description is the largest vein, which is more than five feet thick; others, again, are porphyritic, containing crystals of felspar, of tourmaline, or of mica; and lastly, some of the veins abound in felspar, and resemble veins of compact felspar rather than granite. No where could any connection be traced between the veins and the great neighbouring granitic mass; and most of the veins, even the smallest, appeared insulated. No small masses of granite were observed included in the *killas*, or of the *killas* in the great mass of granite: but small portions of killas, similar to the contiguous rock, were not uncommon occurrences in the granite-veins. A vein of quartz occurs near the *lode* of *Little Bounds*, in *killas*, on the sea-shore: it is three or four inches broad, has numerous branches, contains very good crystals of felspar, and some coarse quartz crystals with plates of mica; and in one place, by a happy mixture of these substances, a compound is formed, which has very much the appearance of common granite, and seems only to differ from it in containing more mica and felspar than usual, and in being softer and less compact.*

Mr. Carne † has remarked, that at Porth Just and Polladen Cove, the granite, in several places, appears to be insulated in the slate; but from the relative situation and size of these apparent bunches, he thinks it probable that they belong to different veins, whose continuity at the surface has been either prevented, or broken, by the slate: and he is also of opinion that the large vein of Porth Just, six feet wide, is not a granite vein, but an elvan-course.

"At Polmear Cove, in Zennor," says Mr. Carne, "the granite veins are as singular and interesting as any in Cornwall. They are from the smallest possible size to nearly two feet in width: they run in several directions; some of them

* Geol. Trans. of Cornwall, vol. i. p. 22. Dr. Davy, on Granite-veins at Porth Just.

† Geol. Trans. of Cornwall, vol. ii. p. 67.

are vertical, others are inclined at different angles, and some are perfectly horizontal. In one part of the Cove, where one of the veins inclines at an angle of full 45°, the slate is fallen from the upper side, and has left a part of the vein exposed to view. Near the same spot is an apparent intersection of one granite vein by another, each of which is about a foot wide. One of them appears to be heaved five feet to the left.*

"In a great majority of instances," observes Professor Sedgwick, "we are unable to trace the veins to the point where they terminate in the granite: the nature of such termination can only be made out by analogy. Fortunately, some parts of the coast expose the base of the veins in such a way as to leave no doubt respecting their origin. The best example of this fact may be seen at the last junction near Wicka Pool. Three large veins rise out from the granite into the slate: the first soon disappears; but the other two, after being cut off by the retreat of the coast, re-appear in two or three successive projections of the cliff. The largest of them, at its insertion into the slate, is not less than fifteen feet wide: at their lower termination, they are all distinct prolongations of the granite itself, and in composition differ from it in no respect whatever. They also contain imbedded fragments resembling clay-slate; and, at a short distance from their base, have the ordinary appearance of the granite veins."†

"A little south of the Pier, at the village of Mousehole, near Penzance," says Mr. Majendie, "the clay-slate ceases, and the granite commences, forming a promontory which runs out in a southern direction from the central ridge. The grey-coloured slate is in strata nearly horizontal, but having a slight dip to the east; it increases in hardness near the junction. The granite, which is generally coarse and porphyritic from the large imbedded crystals of felspar,

* Geol. Trans. of Cornwall, vol. ii. p. 68.

† Cambridge Philos. Trans. On Devon and Cornwall.

becomes here of a finer grain, with black mica, and light flesh-red felspar. On the north it laps over the schistus. At this spot, numerous granite-veins, varying in width from about a foot to less than an inch, pass through the slate; the two principal veins proceed nearly east from the hill above, for more than fifty yards, until they are lost in the sea. One of these, not far from its first appearance, is divided and *heaved* several feet by a cross vein, consisting of quartz intermingled with slate; fragments of slate appear also in the granite-veins. The most remarkable vein, after proceeding vertically for some distance, suddenly forms an angle, and continues in a direction nearly horizontal, having slate above and below."*

Oeynhausen and Dechen published, in 1829, an account of their observations on the junction of the granite and the killas rocks in Cornwall †, in which is a long and circumstantial description of that at Mousehole, illustrated by a sketch. We have already described the large vein ten feet wide as an *elvan-course*, following Mr. Carne, who has thus denominated a similar large vein at Porth Just, though, in fact, no distinction can be drawn between these forms of the granitic rocks; for there is a most perfect gradation, as to size, regularity of figure, and position, from a well marked elvan-course to the smallest granite-vein. On comparing Oeynhausen and Dechen's plan of this vein with ours in the fourth chapter, they will be found to differ much in their bearings; and that their plan does not exhibit the *heave*, is very probably owing to their having visited this place at neap tides,—for which reason they have also not noticed a similar phenomenon in the other granite veins which occur near low-water mark. It may also be observed that, according to these geologists, "the vein c is distinctly to be seen coming out from the main body of the granite, which is as fine-grained as the vein itself." That it may be so connected, is

* Geol. Trans. of Cornwall, vol. i. p. 27.

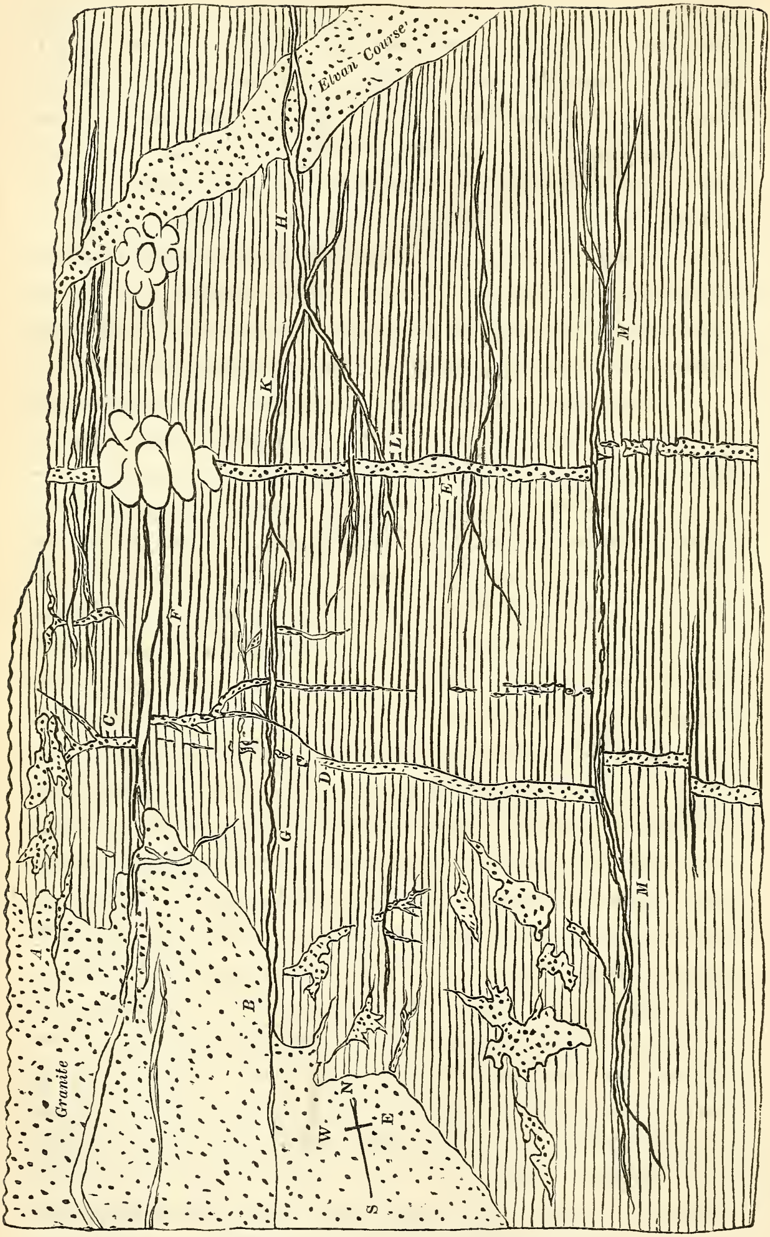
† Philos. Mag., or Annals, vol. v. p. 161.

not improbable; and it is not unlikely that this spot might have been temporarily obscured by shingle or débris from the cliff, when they visited it; but at present the appearance does not agree with their sketch. The granite laid down as the main mass, is an irregular portion of the vein; and slate, at the surface, intervenes between it and the granite.

This junction so well displays the granite-veins, and is so easy of access, that, before concluding the details of these phenomena in Cornwall, we think it desirable to give a minute description of this important example; which may be rendered more intelligible by the accompanying sketch.

The main mass of granite (occupying the left-hand corner of the annexed plan) runs in a north-westerly direction towards the village of Paul, forming the hill immediately westward of the shore at this place. It is porphyritic, and, at a distance from the junction, large grained; but adjoining thereto, the basis, in which the large crystals are imbedded, generally varies from fine-grained to an uniform texture, as in the felspar porphyries. The irregular patches of granite, situated between the southern vein and the main mass, have the same composition: some of these patches are evidently portions of the subjacent mass laid bare by the abrasion of the waves, for several parts of their surface are still covered by persistent laminæ of slate; whether they are all so, remains to be ascertained. The several granite-veins, for the most part, consist of compact felspar; which, in some places, is very quartzose, but seldom porphyritic. The large northern vein or elvan, however, often abounds in crystals of felspar. The slate at the junction, or immediately adjoining the granite-veins, is compact, hard, and finely granular, or crystalline and quartzose. Both the granite and the slate, as already observed, are traversed by fissures or joints parallel with the granite and quartz-veins, which intersect the mass at right angles. Sometimes these lines correspond with the point of junction, but very often they pass indifferently through either rock; and, in these cases, the slate and

Fig. 10.



Granite-veins in slate at Mousehole, Cornwall.
(Ground-plan of the sea-shore.)

granite, whether of the main mass or veins, cannot be easily separated: indeed, it is not always easy to determine where one begins and the other ends; and even then, a difference of colour is the only mark of distinction. It would have been desirable to have introduced these lines into the plan, but they would have confused the details, unless drawn on a large scale.

The granite, at the junction, throws out several small veins, which, however, soon terminate; and in one instance, as at A, the vein runs through both granite and slate. At B, a quartz-vein occupies the line of junction, and is intimately connected with the rocks on either side.

The granite-vein C commences in small branches from a confused mass of an intermediate nature between granite and slate, of which there are several others in its vicinity. After a short course, these branches terminate in one vein four inches wide, which is soon after traversed by a large quartz-vein, by which it is diverted from its course 2½ feet towards the north; it again gives off more branches, which are variously affected by small quartz-veins; and, at last, all gradually dwindle into mere threads, after a course of about 60 or 70 feet: on the same line, a few remote and irregular bunches and strings of granite occur in the slate. The southern branch of the vein C turns toward another vein of granite, D, which begins on the eastern side of a little quartz-vein, but not in contact therewith. At first, its course is marked only by short branches, or merely by a different appearance of the hard compact slate, for about 10 or 12 feet; it then becomes well defined, is 8 inches wide, and gradually increases in size to 11 inches, when it meets with a quartz-vein, M, by which it is heaved 3 feet towards the north; afterwards it continues in the same direction, being 1 foot in width, for about 30 feet, when it is heaved towards the south, 2 feet, by another quartz-vein; and may then be seen running under the sea for more than 100 feet, apparently increasing in size. The granite-vein E may be traced from the cliff to the quartz-vein M, a distance of 100 feet, with the exception of about 20 feet, where it is covered by boulders, as in the plan. In this course, it traverses some quartz-veins, and is in its turn traversed by others without any alteration; but it is heaved by the quartz-vein M about 6 inches, which is the width of the vein at this point. The average size of this vein is about 8 inches; being in some parts 10, and even 12, inches wide. This vein, like D, is at some points indistinct, scarcely to be distinguished from the containing rock; and, here and there, portions of the latter are imbedded in the veins. Of the quartz-veins, the largest and most interesting is F, which may be traced for more than 300 feet. In several places, it is more than a foot wide, containing many elongated drusy cavities, lined with quartz-crystals; its course is very much curved, but the general bearing of the whole vein, like that of the others in this place, is a little to the eastward of north. Just before it leaves the granite, it is composed of small and irregular strings of quartz; and after passing this rock, these become mere threads, which, at several points, are not even marked by a continuous crack in the slate, but totally disappear: a little farther on, however, a larger string appears; and then a large and distinctly formed vein, which continues till lost under the boulders of granite; first of all heaving the granite vein C $2\frac{1}{2}$ feet, as already stated. When describing this vein, Oeynhausen and Dechen state that the junction is heaved in the same way; but if so, the amount of this movement is equal to 14 feet; and if this irregularity of the granite be a heave, then are also the others on the line of junction, in some of which no vein is present: and it is an important fact, as just mentioned, that on the line of this quartz-vein near the granite, there is no breach of any description in the substance of the slate. The quartz-vein G runs in the same direction as the last, a little E. of N., forming the line of separation between the granite and the slate, for more than 20 feet: if, therefore, the appearance at the junction where F enters the granite be regarded as a heave, this also must be viewed in the same light—the movement, however, having been directed to the opposite point of the compass; but we find that the continuation of this quartz-vein has produced no such effect on the granite-vein C, being traversed by its southern, though it intersects its northern branch. The quartz-vein H is particularly interesting. It passes through both the granite-vein E, and the elvan, producing something like a heave in the latter, but does not alter the course of the former: intermediate, however, between these points, it traverses and heaves, for about half a foot, a quartz-vein K, which is intersected by the granite-vein, as also is the quartz-vein L, which might be considered as a branch of H. Here, then, we have facts for and against a motion in the strata, within the space of about 50 feet. The quartz-vein M heaves both the granite-veins D and E towards the north: the former 3 feet, the latter only about 6 inches; the distance between these veins being 30 feet: an occurrence which (as will be shown hereafter) is very common among metalliferous veins. The distance of the elvan, and the granite-vein E, from the main mass of granite on the side of the western hill, does not, perhaps, exceed 100 feet. They appear, as well as the vein D, to increase in size as they recede from the granite: this may be a deception; for, as the shore dips eastward, the veins may become nearer and nearer to the granite beneath, as they retire from this rock at the surface. These veins, in several places, can be seen in nearly a perpendicular position, in sections which vary from 1 foot to 3 feet in depth: and since the same kind of veins abounds in the southern mass of granite, running in a parallel direction, it is probable that a more extended section would exhibit them passing through both rocks. The position, therefore, of these larger veins corresponds with the perpendicular faces of the aggregated concretions; whilst the quartz-veins are situated on those concretionary planes which cross these at right angles, dipping rapidly towards the west. It has already been stated in the last chapter, that the *strike* or course of the granitic and schistose beds declines towards the north at a gentle angle, whilst the laminæ of the slate dip eastward. The elvan appears to occupy the declining surface, as it dips northward so as to cross the laminæ of the slate: and it is worthy of remark, that the strike of the slate gradually winds round this granitic promontory; so that, approaching St. Paul, it becomes N., and at length N.W.; which fact may account for the deviation of the elvan from a course parallel with the granite-veins.

The excellent examples of Cornwall have led us into lengthened details, but not greater than the importance of this topic requires: it is time, however, to turn to the granite-veins of other countries.

On the shore beyond Bunawe, says Macculloch*, in his account of the Mountain Cruachan, the junction of the granite with the schist is clearly seen. Two distinct varieties of granite appear in this place: the one, a granite according to the strictest acceptation of the term, consisting of reddish felspar, quartz, and mica; the other a syenitic granite, or a compound of white felspar, mica, and hornblende. "These are co-existent in every respect, and seem to pass into each other, while both of them ramify in a similar manner through the schist; a sufficient proof, if any were wanting, of the geological identity of these two rocks, which have so improperly been distinguished by the accidental presence or absence of the single ingredient, hornblende."

The schist which lies in the immediate vicinity of the granite is highly indurated, and gives fire readily with steel; in other respects, it retains its general character, a laminated structure, and alternating stripes of colour.

Large veins proceed from the great mass of the granite, and ramify into innumerable small divisions, penetrating and traversing the schist in every direction. Although these veins sometimes run through the schist in a distinct form, just as they do in the junction of Loch Ranza, yet in many places they are intermingled with it in the most remarkable

* Geol. Trans., vol. iv. p. 120.

manner. Crystals of this hornblende may be observed shooting far into the body of the schist, so as to render it often difficult to assign the limits of each rock: and, in a less degree, the quartz and felspar exhibit the same appearance. Together with this, the schist is singularly contorted, being bent, broken, and intermingled in a most confused manner with the rock that traverses it, while distinct detached fragments are often involved in the mass of the granite: in many instances, these fragments either exhibit at their edges a change into a substance resembling basalt, or are actually converted into a black matter, which has, at first sight, the aspect of a fine-grained hornblende-rock, or a basalt of the blackest hue, and which only an accurate inspection discovers to be modified fragments of schist.

The district of Rannoch, observes the same author*, offers a multiplicity of granite-veins, which are so confounded with each other, and with the rocks which they traverse, that their appearance cannot be accurately described. They frequently vanish so imperceptibly, both in the quartz-rock and the mica-slate, that a perfect passage from the one to the other is visible, while the accession of additional veins, traversing and often shifting the already intricate structure, increases the unexampled confusion which reigns among them. The granite is often imbedded in detached lumps in the schist; and it is worthy of remark, that, however minute they may be, contrary to the granite-veins of Glen Tilt and Corpach, their character is perfect even to their minutest division.

The granite-veins at Glen Tilt are found traversing strata of limestone-schist and quartz-rock; and possess a farther interest, independent of their geological relations, as having afforded Dr. Hutton one of the original arguments on which his theory is founded. Having already described all these rocks, and the nature of their connection, the granite-veins by which they are intersected may be more easily understood.

* Geol. Trans., vol. iv. p. 130.

At the junction of the mass of granite with the strata, innumerable processes, or veins, may be seen spreading out from the granite in every possible direction: these veins are occasionally of large size, but in general they are small, and even do not exceed a thread. Although they can be traced into the large mass of granite, they sometimes appear both to originate and end in the limestone, presenting rather the aspect of detached lumps and irregular processes, than of veins. So confused is this interference, that a portion of granite is often found entangled in the limestone, and insulated parts of the latter rock are sometimes contained in the former; and the smaller veins may be seen reticulating the schist and limestone in the most intricate and amusing manner. "As long as these veins continue of a few inches in breadth, their mineral character is the same as the adjoining granite: as they diminish, however, the hornblende gradually disappears; although, in the cases in which the vein traverses hornblende-schist, this mineral is increased in quantity. But the vein of mixed quartz and felspar is the most common; and this, as it continues to diminish in size, ultimately becomes mere felspar, or else a compound of felspar and quartz, so intimate, that the magnifying glass discriminates the particles no longer, and the whole is only distinguishable from common felspar by its peculiar fracture and superior hardness." *

In short, wherever granite-veins have been observed at the junction of the granitic and schistose rocks, they exhibit similar phenomena to those of Cornwall. With very little alteration, therefore, we may, with Mr. Carne †, sum up the evidence on this subject in the following manner: —

1. The composition of the granite-veins is generally different from that of the main body of granite, and it is very frequently of a much smaller grain. It will, however, be

* Geol. Trans., vol. iv. p. 265. *et seq.*

† Geol. Trans. of Cornwall, vol. ii. p. 69.

found to resemble the veins, courses, or beds which form an integrant part of the central mass.

2. The slate which is contiguous to the granite-veins, is frequently much harder, more crystalline, and its texture is, in general, less schistose than that which is more distant: and it often exhibits mica, hornblende, or other minerals in a distinct form, the nature of the mineral depending on the composition of the containing rocks.

3. Some granite-veins are closely connected with the slate, both being intimately united and inseparable; and indeed, sometimes, as in the case of Rannoch, one of the component minerals of the veins is crystallised, and its crystals penetrate and are contained in the slate as well as in the vein: it often happens, however, that the veins can be easily detached from the slate, and have distinct walls; that is, an open seam or joint divides them from the slate.

4. Detached portions of the slate, having the appearance of fragments, are frequently insulated in the granitic veins, and sometimes indeed also occur in the main body of granite; and, *vice versâ*, similar portions of granite are often completely enveloped in the slate.

5. These veins are sometimes so abundantly and intricately blended with the slate, either one or the other predominating in the mass, that the whole is involved in apparent confusion; whilst in other cases the slate reposes on the granite without any appearance of dislocation or disturbance, and is traversed by well-defined granite-veins.

6. These veins have, in some cases, been traced to the main mass of granite, with which they appear to be in complete union, and to form one body, losing entirely their character as veins; whilst in other instances these veins have been found to continue their course through the granite as well as the slate.

7. The granite-veins have no general direction or position; they run towards every point of the compass, and dip at every angle from the horizon to the perpendicular.

8. These veins are sometimes straight, and pretty regular in their thickness; but in general they are more or less tortuous, and gradually become smaller as they recede from the granite.

9. It occasionally happens that where these granite-veins occur, the slate is intersected by numerous small quartz-veins: some of these are traversed by the former; others, on the contrary, traverse and heave both the granite-veins and the other quartz-veins.

CHAPTER IX.

ON THE MINERAL AND METALLIFEROUS VEINS IN PRIMARY ROCKS.

Our knowledge of veins very imperfect — and too hypothetical — the definition of veins not correct. — The following details on this subject entirely drawn from Cornwall. — Description of veins as seen on the sea-shore, in quarries and similar open situations. — Of small concretionary veins, — of larger veins not confined to individual rock-concretions, — but traversing one or more layers or strata. — These commonly called contemporaneous and true veins — but are identical, only differing in size. — Large quartz veins intersecting both the granite and slate, — at St. Michael's Mount, — at Mousehole, — and at Cape Cornwall. — The connection between metalliferous veins and the containing rocks. — Veins curved both in their course, and underlie, — as at Polgooth and Huel Jewel mines. — Veins intersect each other both in their length and depth, accompanied by apparent movements, — as at Dolcoath, Weeth, Ting Tang, Huel Friendship, South Huel Towan, and Huel Peever mines. — Interference of veins and elvan-courses, as at Polgooth and Dolcoath mines. — Veins similarly affected without the intervention of veins of any description, — as at Balnoon and Ding Dong mines.

Before concluding this sketch of the primary rocks, it is requisite, in order to complete their description, to make a few observations on the mineral and metalliferous veins by which these rocks are traversed. The details on this subject will be almost entirely drawn from Cornwall, where the phenomena of veins have been more extensively and more minutely investigated than in any other country; and, indeed, as far as works on this subject in our language are concerned, Cornwall has been the principal source of information. The metalliferous veins contained in the secondary rocks are not unimportant, either in an economical or scientific point of view; but to enter on their examination, at present, would be departing from the plan of this work, and would, if they were fully treated of, require an entire volume. Besides, it is desirable that the subject of veins should be carefully described under distinct heads, according as the rocks with which they are associated vary in their nature: and when a large body of facts has, by these means, been collected, then our generalisations may be placed on a more permanent basis; but, at present, the facts which we possess concerning veins are fully equalled, if not exceeded in number, by speculations on their nature and origin.

The vast importance of an accurate knowledge of veins to our commercial welfare and prosperity, is generally admitted; and geologists, also, have always regarded veins, not only as a curious and interesting feature in the structure of the earth, but also as affording valuable evidence concerning the internal movements and convulsions which our planet has periodically experienced. Notwithstanding, however, the high estimation in which this subject is generally held, it is astonishing how little progress has been hitherto made in this department of geology: every other branch of the science abounds with copious and good descriptions, which are daily increasing in number and in importance; whilst that of veins scarcely possesses any plain and honest details unencumbered with hypothesis. Indeed, the low state of our knowledge of these curious phenomena is plainly denoted by the neglect with which they have been treated in the most recent and most esteemed geological publications. Thus the student looks in vain for any practical information on this subject in the voluminous work of Lyell on the Principles of Geology: and in the Manual of De la Beche, he must rest contented with some short details; indeed, the author has apologised for the brevity with which he has treated this branch of the science, and adds, that his notice of it "is solely intended to call the attention of the student to a few interesting circumstances." We rather suspect that the confusion of facts and theory in the descriptions of veins, rendered this subject unfit for the pages of his practical work. In Macculloch's System of Geology, also, although the account of veins occupies a few more pages, yet it does not convey an accurate notion of a vein; and is, as in every other work, so blended with hypothesis, that the student cannot distinguish fact from conjecture.

This fault, both in our elementary and systematic works, is certainly to be regretted: it is not, however, attributable to these eminent geologists, but to the mode in which this part of the science has been treated; and their names are only here adduced as authorities to show the truth of our observation, that the knowledge of veins is very defective.

This stricture may not appear to apply to the descriptions of those veins which occur in the primary rocks, and more especially of those in Cornwall, which have attracted so much attention, and have formed the theme of some essays of no little merit, as those of Mr. W. Phillips and Mr. Carne. But it will be found that even these local details are haunted by the same evil genius, the blending of fact with hypothesis. Thus, Mr. Carne's paper on Veins, replete as it is with much important information, is professedly framed on a theoretical basis, "an attempt to ascertain the relative age of the Cornish veins, on the principle that a vein which is traversed by another vein, is older than that by which it is traversed." So that the attention is necessarily almost entirely directed to a single point, which is only one of the many interesting phenomena exhibited by veins: the object of the paper has been well accomplished; but we have always thought that the author would have conferred a greater benefit on the science, if, from his store of practical experience, he had imparted more lengthened and descriptive details of each leading example.

The student, or rather the geologist, (for who is not a student on this subject?) after having perused these papers on the veins of Cornwall, returns to them again and again, and still his idea of a vein is not more distinctly defined: he feels satisfied, indeed, that he knows what a vein is, and so does the merest tyro; but, as in the case of the word *stratum*, when he attempts to offer an accurate definition, then he learns that his notion of it is vague and objectionable.

What is a vein? There are many kinds of veins. Certainly; but what is the nature of those veins occurring in primary districts, which are metalliferous, and have been explored in Cornwall by workings, many thousand miles in length, and which are commonly known as true veins? Surely there can be no hesitation in answering this question, since the subject has been so extensively examined. Werner has, indeed, stated, and succeeding writers have adopted his views, that "a true vein is understood to be the mineral contents of a vertical or inclined fissure, nearly straight, and of indefinite length and depth." Now this statement is open to two rather serious objections: in the first place, it cannot be demonstrated that these veins were originally fissures; and until this be done, it ought not to enter into the terms of a definition: and, in the next place, no metalliferous veins in Cornwall strictly answer to this description. Mr. Carne must, in some degree, have been sensible of this discrepancy, for when endeavouring to point out the difference between true and contemporaneous veins, he has remarked that "there are few veins which can be brought to the test of all these marks; and there are, probably, exceptions to some of them: some veins which are very short are, perhaps, true veins; and others, of considerable length and width, and tolerably straight, may, possibly, be contemporaneous." *

It is evident, therefore, that this account of veins is very imperfect, and that a good definition is still a desideratum. In order to accomplish this object, it is necessary, in this as well as in every other branch of natural science, to obtain, in the first place, numerous and accurate descriptions of veins. So that, when we look around, and find that we do not possess such data, not even, indeed, a single instance of a

* Geol. Trans. of Cornwall, vol. ii. p. 52.

minute and faithful delineation of a vein, it cannot be very surprising that the task of definition has been so imperfectly performed. This may appear to be a startling assertion, but it is made advisedly; and, indeed, the reason of this deficiency is obvious.

Hitherto we have been indebted almost entirely to practical men for information on this subject; and it cannot be expected, from this source, to obtain such minute and circumstantial details, such nice and delicate discriminations, as are requisite for scientific purposes: indeed, the nature of their pursuit is, in some measure, incompatible therewith, their object being only to obtain the ore, and that as expeditiously as possible. It may be hoped that this deficiency, as far at least as Cornwall is concerned, will be soon supplied, by the labours of Mr. Henwood, who has nearly completed his survey of the mines.

In the meantime, however, it is necessary to give a general idea of the Cornish veins, because they afford some important evidence, which will be required in the following discussion. The descriptions about to be offered have been drawn from veins which occur on the sea-shore, in quarries, and in similar natural and artificial sections; from these sources much valuable information may be gained concerning the position of veins, the nature of their connection with the containing rocks, and many of the appearances produced by the interference of one set of veins with another. These exhibitions, however, are most satisfactory, when the view is confined to a horizontal section or ground plan; whilst the phenomena displayed by veins, during their descent, are best investigated in the mines.

When a section of the primary rocks is closely inspected, it is found that no individual rock continues pure and uniform in its composition for any considerable extent; and far more commonly each of its constituent blocks or concretions exhibits a striped or variegated appearance, on account of numerous irregular veins which intersect its mass. These minute veins are more or less simple in their composition: very frequently they consist, for the most part, of a single mineral, the nature of which generally bears some relation to the constitution of the containing rocks: thus, quartz-veins are found in all rocks, which might be expected, since all rocks abound more or less in silica; but they are most frequent in those rocks wherein this earth predominates; so, likewise, calcareous veins occur in rocks, into the composition of which lime enters; and veins of asbestos, steatite, and other magnesian minerals, characterise serpentine, euphotide, and other rocks of a congenerous nature; and, lastly, whatever may be the peculiar and distinguishing mineral of any series of granitic or schistose rocks, whether hornblende, chlorite, shorl, actynolite, or mica, small veins and patches of the same substances impart to the mass an appearance more or less variegated. Sometimes, however, the substance of these veins is compound, exhibiting either distinct or homogeneous crystalline mixtures of two or more minerals, which very commonly are only varieties of the rock in which they occur: thus, veins and irregular portions of fine-grained granite, of syenite, of shorl-rock, and of other granitic species, are frequently completely enveloped in various kinds of granite; and hornblende-rock, actynolite-rock, and other members of the schistose group, contain small veins of a more crystalline nature imbedded in the homogeneous varieties, and *vice versâ;* these occurrences, however, are not very conspicuous, unless rendered obvious by a partial decomposition, by which the harder or more crystalline parts are brought into *alto relievo* on the surface of the blocks.

Such is the composition of the small or concretionary veins of the primary rocks: the next points for consideration are, their connection with the rock, and their structure.

A fresh fracture, or, indeed, the external surface, if the rock be of a durable nature, shows that the substance of these veins is often intimately blended with that of the rock; so that it is impossible to say where the one begins and the other ends: but this is not always the case; and, indeed, even where one part of a vein appears to be in the former predicament, another part is bounded by a distinct line, on each side of which the substance of the vein and the rock are strongly contrasted.

So, when the rock has suffered from the decomposing action of the elements, these veins often exhibit perfect walls, or even an open seam or crevice, the chemical change being more rapid at those points where substances of a different nature come into contact: but in those veins, or in those parts of veins, as in the case just mentioned, in which the junction is accompanied by a perfect transition, decomposition does not develope this disunion of parts.

As to size, length, and other dimensions, these veins exhibit every variety within the limits of the containing block or concretion: as regards their form, they are either straight or tortuous, more or less uniform in breadth throughout their course, or, tapering at one or both ends, they terminate in one or many filaments; and, lastly, when they meet in opposite directions, some appear to traverse others, and the disconnected veins either continue in the same lines on both sides of the interposed veins, or in parallel lines, at some distance from each other, on the opposite sides of the latter veins; in short, exhibiting on this small scale all the phenomena which have been observed in the largest veins; and sometimes these characters are distinctly marked, even in hand specimens, as in the slate of St. Agnes, and in the granite of Carclaze, in both of which the minute veins are metalliferous.

Let us now advance a step farther, and we shall find that when these rock concretions are not individually contemplated, but in the aggregate, as united into a layer or bed, the same appearances are still exhibited: larger veins, but similar in composition to those just described, traverse different concretions, not unfrequently penetrating through their very substance, and even intersecting and anastomosing with the lesser concretionary veins; more commonly, however, the larger veins are interposed between the boundaries of the individual concretions of the rock. In the latter case, the veins sometimes unite the blocks into such a firm mass, that they are not separated by the action of the elements; but, in general, these veins, by being more crystalline in the middle part, are readily disunited along this partially open line or chain of drusy cavities: and thus it is, that we so often find one or more sides of weathered rocks coated and protected by the moiety of a vein; in granite, for example, the blocks often exhibit a surface of quartz, and in serpentine, of steatite or asbestos.

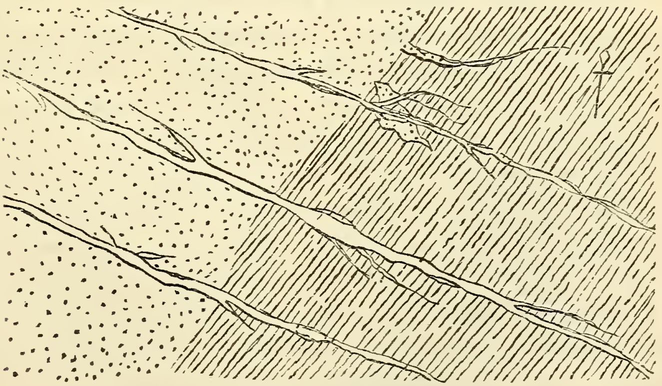
Proceeding still farther, we arrive at the immense masses of rock resulting from the aggregation of the layers and strata: on this large scale, we do not find so great a diversity in the mineral composition of the veins, as in those minute ones, that are confined to the concretions of rocks; but still this is in perfect keeping with the general design, for the minerals which produce these rare concretionary veins, do not enter into the construction of extensive masses of rocks, but are confined to a few and limited localities. But, with this exception, where is the line of demarcation to be drawn between contemporaneous and true veins? Mr. Carne must have been convinced of this difficulty, by the establishment of his order of doubtful veins, a debatable land, subject to the constant inroads and reprisals of the true and contemporaneous orders; and the best way to terminate this contention, is by an act of union and consolidation of the contending parties under one dominion: indeed, to continue their separation can be but a conventionary act, for they are not divided by any natural boundaries.

It may, however, be asserted that there is a difference, that true veins do not terminate in their length and depth; but the supposed nature of their origin from fissures, shows that they must be limited in these directions. This opinion may be traced to the miners, who have been led to this conclusion, because veins generally taper away and terminate in strings: and, in many instances, by following these strings, they have found them to enlarge again into a workable vein; or because, many mines having been worked on the continuation of the same line, they have supposed that the vein is one and the same in all these places. On the other hand, veins have been often found entirely to die away, or disappear, not only in mines, but also in the rocks on the sea-shore: and even if such examples had not been detected, the extent of mines is comparatively insignificant to warrant the assertion, that veins are indefinite in length and depth. Granting, however, that some veins are of considerable and unknown dimensions, still there will be found no boundary between these and those smaller veins which have been commonly called contemporaneous.

An examination of two or three examples of veins on a large scale will, however, convey a better idea of their nature; and, in order to avoid any mistakes, we will select those which traverse both the granite and the slate, and which, therefore, cannot be considered as contemporaneous by the supporters of the prevailing Plutonic theory.

In the first place, on the S. E. side of St. Michael's Mount, some metalliferous veins may be easily examined when the tide is out.

Fig. 11.



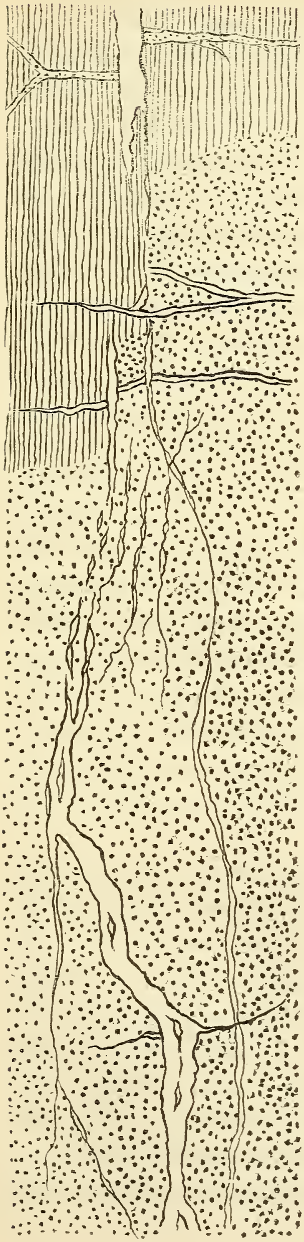
Quartz veins at St. Michael's Mount.
(Ground Plan.)

These veins are exceedingly numerous, and parallel with each other; and are almost perpendicular. They are in general small, very seldom exceeding a foot in thickness. The quartz or matrix of these veins is frequently crystallized in the central parts, so as to form drusy cavities or elongated openings, which are often lined with crystallised mica, tin ore, tungstate of iron, and other minerals. In their course they send off numerous branches, which often ramify in the rock, and are sometimes reunited with the main vein. They do not run in a straight line, but in one which is more or less undulating; and are not of an equal breadth throughout, expanding, in some places, into large bunches, and in others contracting to the size of a string; and this irregularity is more prevalent in the slate than in the granite. The rock, whether slate or granite, adjacent to these veins, is always more quartzose than at a distance therefrom, so that they gradually pass into each other; and the boundary of the veins is more seldom marked by the joints or open seams, or walls as they are usually termed, than commonly happens in other localities. Heaves are of rare occurrence: but it may be remarked, that, in one instance, a vein seems to have been heaved about three inches by the N. and S. joint of structure, but the same line intersects other parallel veins without producing the same effect.

Near the pier at Mousehole, also in Mount's Bay, a large quartz-vein traverses both the granite and the slate, and may be examined for more than 150 feet in length. (See *fig.* 12.)

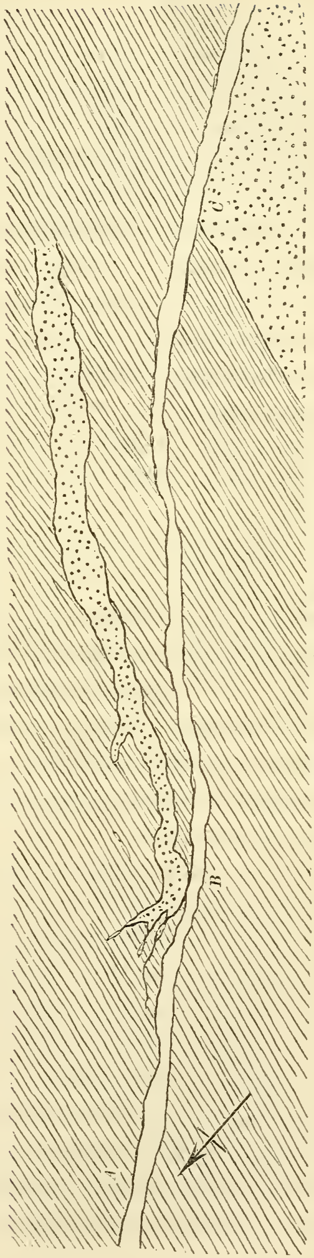
It will be perceived, that the width of this vein is much exaggerated, in order to render its nature more visible; for, if it had been drawn in proportion to the above scale of its length, it would have been reduced to a mere line. Its average size is about one foot in thickness: at the southern end it sometimes attains to fifteen inches, and then generally contains large drusy cavities lined with quartz crystals; but near such enlargements it will suddenly contract its dimensions to three, or even two inches; and in the middle of its

Fig. 12.



Quartz veins at Mousehole.
(Ground Plan.)

Fig. 13.



Little Bounds Lode, near Cape Cornwall.
(Ground Plan.)

course, it becomes so assimilated with the granite, that its presence is only marked by short unconnected strings, and even these, at the junction of the granite and the slate, are entirely wanting. The northern extremity of the vein is more regular, varying, however, from twelve to five inches in thickness, and having an undulating course: as it approaches the granite, it heaves a granite vein to the left, and five feet farther on, ends in ramifications before reaching the granite; a fine open line, or seam of structure, continues for six feet, which, next the granite, is in two or three places, for a few inches in length, lined with minute crystals of quartz, but for eighteen inches beyond these small veins, there is no signs of strings, cracks, or continuations of any description: the quartz vein is altogether obliterated. A little farther on, in the direction of the southern extremity, two branches, or distinct veins, run side by side, then both become obscure, and again continue their course, as indicated in the plan. The dip of this vein is not clearly shown, but it appears to be nearly perpendicular: it is, throughout the greater part of its course, distinctly separated from the rock by open seams or walls; but at several places, both in the granite and the slate, it is most unequivocally united therewith by mineral transitions; these rocks also enter into its composition, and the seams by which they are divided into concretions often intersect the vein.

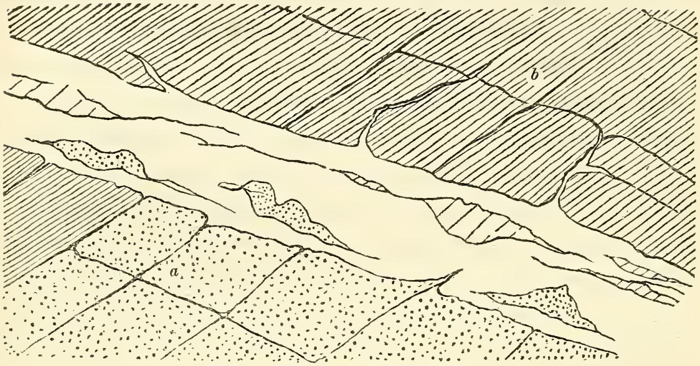
On the rocky shores of St. Just, however, the veins are frequently exposed for a considerable distance; and it is also an important circumstance, that they are metalliferous, and very many of them have been extensively explored. A vein of this kind occurs at Porth Just, Cape Cornwall, the *lode* of Little Bounds mine, and is what is technically termed a *master-lode*, on account of its size and regularity. The rough diagram (*fig.* 13.) will show the bearings of this vein, and of an adjacent *elvan-course*, or large granite-vein; but it must be remarked, that many parts of its course are obscured by loose pebbles and boulders.

The distance of the Little Bounds lode, from the cliff to the gap at the extreme point of Cape Cornwall, exceeds a quarter of a mile; and along this course the vein is well displayed in several places, running in an undulating manner; the part next the Cape points more towards the north, while the middle approaches nearer to the west; but the original direction appears to be recovered at Little Bounds, so that a line drawn through the two extremities, would bear about N. W. and S. E., the usual direction of the *lodes* in St. Just. It is evident by the diagram, that a considerable portion of the lode is left on the southern side of such a line; and it is very probable that, if the lode could be traced farther in its northern course, it would be found to pass as much on the northern side of this line, just as the lesser curves of the same lode may be seen to fluctuate between the opposite points of the compass.

Let us now turn our attention from this general view to a close inspection, in order to ascertain the composition of the vein, and the nature of its connection with the rocks which it traverses; and for this purpose three points will be selected, denoted by the letters A, B, C, in the general plan.

The part of the vein marked C, occurs on the shore immediately below Little Bounds mine, and is situated between the granite and the slate. In the cliff, a perpendicular section of the same is exhibited, but the rock on either side is much altered by decomposition and disintegration; on the shore, indeed, it has not perfectly escaped from the action of the elements, but is so slightly changed, that its nature is very apparent; in both places, but particularly in the former, the vein is regularly bounded by open lines or crevices, and parallel thereto, both the vein and rock differ in structure from the mass of these substances, having what is commonly called *walls;* at some points, however, in the spot C, the vein and the adjoining rocks are intimately united, penetrating into each other, and participating in the same mineral composition. The annexed figure will show the position of the different bodies at c.

Fig. 14.

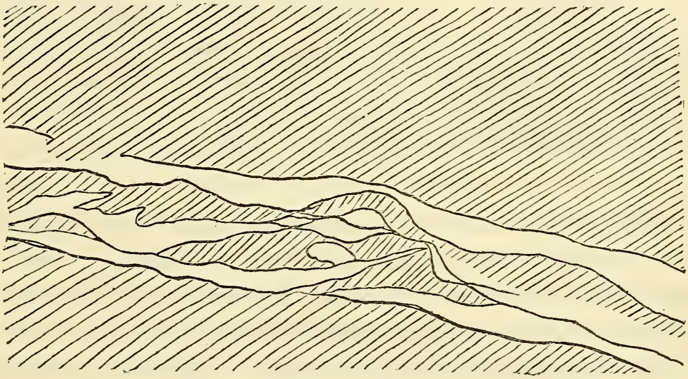


Part of Little Bounds Lode at c.

The granite is disposed in layers parallel with the vein, as denoted by the open seams: at a distance from the vein this rock is distinctly granular, composed of felspar and quartz in the usual proportions, with scales of black mica. Within a few layers of the vein, the quartz begins to predominate over the felspar, and the mica is rather increased in quantity; then the basis of the granite becomes very fine-grained, and abounds in nodules and strings of quartz; a little nearer the lode the texture of the granite is close and uniform, much tinged with oxide of iron, and very hard: the mica has disappeared, and its place is supplied by chlorite, which occurs in patches intimately blended with the basis of this rock: lastly, it gradually becomes perfectly quartzose, till it terminates in the quartz-vein, but at the point of contact therewith, it is very ferruginous: the transitions of the slate, on the other side, are of a similar nature; being, next the vein, a hard quartzose rock, only differing from that on the granite side in its dark blue colour, in those parts that are not tinged by the iron. On the line of junction between the vein and rock, open seams occur at some points, but not at others; and sometimes, when present, do not precisely separate the vein from the rocks, but cut off portions of the latter, in which case they are intimately connected with the quartz of the vein, just as described in the two last chapters as happening at the junction of granite and slate. The substance of the vein is not uniform, but the pure quartz is intermixed in patches, stripes, or veins, with the quartzose varieties of the adjacent rocks, sometimes the one and sometimes the other prevailing in quantity.

The part of the vein marked A is entirely situated in slate, and is about a hundred feet from Cape Cornwall: its size and direction is distinctly defined, though quartz does not here, as at C, form the greater part of the mass.

Fig. 15.

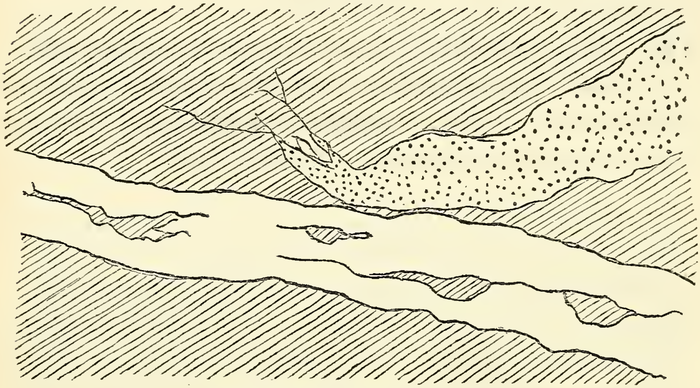


Part of Little Bounds Lode at A.

Here the quartz forms an irregular band on either side, between which the vein is composed of variously formed stripes or veins, some of quartz, but the greater part of the same kind of quartzose schist, which bounds the vein on either side, partaking, however, more of quartz, into which it continually passes by the most gradual transitions. The slate adjoining the vein is, as at C, very ferruginous, and forms, as it were, walls of two or three feet in thickness, which accompany the vein throughout its course; and might therefore be considered as forming part of the vein as well as the central quartzose part. On either hand this ferruginous slate graduates, at many points, both into the slate and the vein, though, generally, they are separated by longitudinal seams, whilst the cross seams of the slate often penetrate into the vein.

At B, the vein is more regular, but is interesting as the point at which the granitic elvan or vein comes in contact with the lode, as shown in the general plan.

Fig. 16.



Part of Little Bound's Lode at B.

This elvan consists of compact felspar which here and there is porphyritic, and in some parts very micaceous; when it approaches the vein it becomes quartzose, and gradually passes into the vein, as it does also into the slate at many points throughout its course; and, what is particularly worthy of remark, it terminates not far off in small veins and strings, and at its other extremity, near the spot where the fishing boats are drawn up, it becomes so blended and intermixed with dark-coloured schistose rocks, that it is difficult to determine where the one begins and the other ends.

By these examples we learn, that large metalliferous veins, like the lesser ones which are confined to rock concretions, though they may sometimes appear to have walls or way-boards, yet these are not essentially necessary, being often only found in certain parts of the veins, and may therefore be attributed to accidental circumstances, such as the peculiar manner in which the substance of the lode was aggregated; the occurrence of a smaller vein of a different mineral parallel, and sometimes coincident, to the sides of the larger; but far more frequently to the subsequent formation of seams or fissures, by the alteration of the rock at the junction of the veins, resulting from decomposition, the effects of the percolation of water, or of the action of the elements. How can we otherwise account for the fact, that many parts of those veins, exhibiting what has been called regular walls, are intimately connected with the adjacent rock, not only as it were by a mechanical union, but often by a transition of mineral composition, so that in granite the union is generally effected by the rock gradually becoming more and more quartzose, and in the slate it is also accomplished by the latter undergoing a like change? Sometimes indeed the vein itself, at these points of union, appears to partake of the nature of the containing rock; but much more commonly it entirely includes portions of the rock of various dimensions, according to the size of the vein. When the portion of rock thus circumstanced is considerable, it appears, as seen on the sea-shore, as if the vein had divided into two branches, which embrace a large angular piece of rock and then reunite; but, in mines, these masses of detached rocks, like the minute portions, are found to be completely enveloped; and this is of such common occurrence, that the vein is said by the miners to have taken *horse*. Now, these included portions of rock, whether they be small or whether they be large, exhibit the same relations to the vein as the latter does to the main mass of rock; that is, sometimes they appear to be clearly defined and distinctly separated from the quartzose part of the vein, but, at other times, they pass into the substance of the vein.

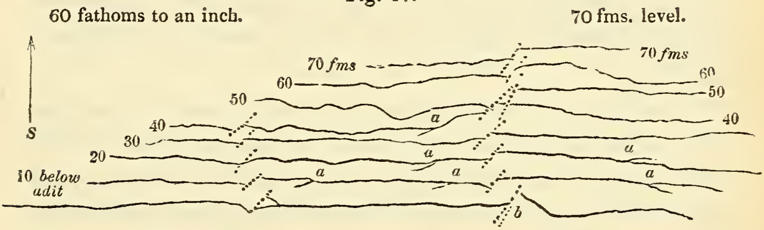
There is scarcely a mine in Cornwall in which the veins do not contain more or less of these angular portions of the adjacent rock, and in which this phenomenon of transition may not be observed: and sometimes these portions of rock so predominate over the quartzose part of the vein, that the latter seems only to cement the former together: and, indeed, some lodes, as at Lanescot mine, have been found to consist almost solely of rock, full of irregular veins and bunches of quartz of various forms and dimensions. And in veins abounding in the substance of the rock, the metallic minerals are not confined to the quartzose part, but are also disseminated throughout the included pieces of rock in grains, nodules, and even in small veins: and in this case the ore has all the appearance of being contemporaneous with the rock in which it is enclosed.

Extreme examples of this kind of veins, if viewed for the first time, and without a knowledge of the intermediate links by which they are connected with regular quartz-veins, would not, perhaps, be regarded by geologists as veins; indeed, they pass at last insensibly into a regular layer of rock, and if the ores still continue in numerous minute veins, we have such a metalliferous rock as has been denominated a *stock-work* by the Germans, an example of which occurs in Cornwall, at the open mine of Carclaze.

Another example of veins, which is not unfrequent in Cornwall, is when a layer of rock, differing from that adjacent either in the degree of hardness, colour, or of an entirely different nature, as an elvan or porphyry, contains so much ore in bunches or veins as to be worked as a lode. In these cases, also, the geologist would not recognise such deposits as veins; and yet they differ in no respect either in the manner or distribution of the ores, in their mode of connection with the adjoining rocks, in their course, dip, or in the usual phenomena of intersections, when they meet with veins of ordinary descriptions. Indeed, what is still more to the purpose, such deposits have been laid down as lodes in the sections descriptive of the phenomena of veins, without their having been distinguished in the miners' reports from lodes of the ordinary character.

It has been already stated, that the veins in the cliffs, and and on the sea-shore, are not straight in their course, but run in an undulating line, the curves of which are various and irregular: and, along their whole length, they continually throw out branches and fibres in every direction; and by which the ends of a curve are sometimes connected. In Polgooth, not only the veins, but the courses of porphyry, are similarly curved; and that too on the line of their dip, as well as on that of their lateral extension. According to Mr. Henwood's survey, this is of very general occurrence in the veins of Cornwall; and he has obligingly furnished me with the following illustrative example, from Huel Jewel mine (near St. Day), which, below the adit, is entirely situated in granite; and has afforded considerable quantities of the black, grey, and yellow sulphurets of copper, but very little tin ore.

Fig. 17.



Huel Jewel Mine. — (Bird's-eye View.)

"The continuous lines denote the direction of the *lode* at various levels: so that, if the dip of the lode were constant, all the lines would have been parallel and equidistant, since the successive levels are ten fathoms below each other. In fact, the lode is as curved in its descent as in its course, and thence the irregular appearances which it presents at each level. The deviation from parallelism with the lode at the adit level gives the variation of the dip at various depths; it is, however, always towards the north. The two series of dotted lines denote two *flucans* (or friable, earthy veins, having a more northerly direction than the regular E. and W. metalliferous veins); and the distances between their respective parts denote the variable quantity of their dip." The phenomena of intersection which these flucans exhibit, will be referred to hereafter.

These facts are diametrically opposed to the prevailing opinion, founded on the reports of those who have written on the Cornish veins. It is true, that a line drawn so as to intersect the two extremities of these veins has a regular bearing; but to call such veins straight on this account, would certainly not be less incorrect than to apply this term to meandering rivers.

The characters which have been already described, may be considered as of a general nature, being more or less applicable to each individual: but we now proceed to detail those phenomena which result from the interference of veins with each other, occasioned by veins of a parallel course dipping to opposite points of the compass, or to the same point at different angles; or by veins running in different directions.

In veins thus circumstanced, some are found to continue their course uninterruptedly, so as to intersect others which often terminate abruptly against the cross-vein. The detached parts of the intersected veins sometimes continue their course in the same direction, but, more commonly, they cannot be traced in the same line, the part on the opposite side of the vein being at some distance therefrom, though running in a parallel direction. In short, the intersected veins exhibit such an appearance as might arise from the motion of the rock on one side of the cross-vein, or from movements on both sides, in a contrary direction: thence, the miners have attributed these occurrences to *heaves* and *throws;* and the same views have been adopted by geologists.

Now, these phenomena may be frequently observed on a small scale in blocks of marble, serpentine, and other rocks; or, indeed, even in hand-specimens, the schistose rocks of of Cornwall abounding in such illustrations, in which the veins also often differ in mineral composition; the intersected veins being sometimes metalliferous, traversed by one or more quartz-veins. In these instances, the veins are frequently so small and short, and moreover so intimately united with the containing rock, that no one has disputed their contemporaneous nature; but it has been supposed, that the appearances of motion are deceptive, and to be explained on other principles. "In a multitude of contemporaneous veins," observes Mr. Carne, "some may appear to be heaved; but the apparent heave seldom affects more than one vein: and it is, in general, easy to perceive, that what appear to be separate parts of the same vein, are different veins, which terminate at or near the cross-vein."* This description equally applies to what are called *true* veins or *lodes;* the intersected parts appear to have been moved, but such a displacement is only apparent, not absolute: and it might, therefore, be a safer course to doubt whether the large veins have experienced any movements, since the small ones display similar appearances, which cannot be referred to a mechanical cause. We must not, however, farther anticipate the discussion on this subject, but proceed to offer some examples of this phenomenon on a large scale, for which we are indebted to Mr. Henwood: premising that he uses the mining terms, in reference to *heaves* and *throws*, in the same sense as Mr. Carne.†

1. *One vein intersects another with or without producing an apparent heave.* This proposition is so simple, that it needs no illustration, when a vein is only examined at a given point; but if the vein be followed in its downward course, it will be found, that "the extent of the heave is not always, or indeed usually, the same at all depths. Thus, the main *lode* of Ting Tang mine (near St. Day, intersecting granite and

* Geol. Trans. of Cornwall, vol ii. p. 52.

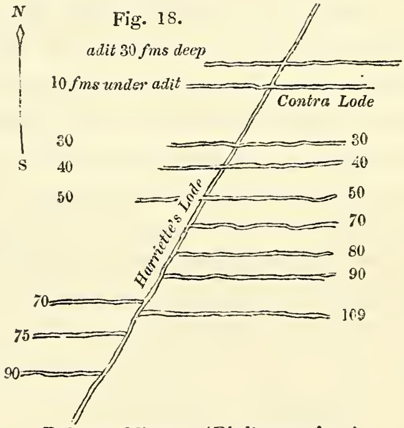
† Idem, p. 86. —"I use the term *heaved*," says Mr. Carne, "as applicable only to a longitudinal shift of the vein; and, *thrown up* or *thrown down*, to those shifts which take place on the meeting of two veins, underlying in different directions, in their downward course. In describing the *heave* of *lodes* as *to the right* or *left*, I mean, that when lodes are heaved by other veins, they may be found on the other side of the traversing veins, by turning either to the right or left hand. I use these terms in preference to the points of the compass, because, in whatever direction a miner may pursue a lode, a right or a left hand heave is precisely the same on both sides."

slate) is heaved by the western *flucan**, towards the right hand, and the greater angle, at

90 fathoms deep,	21 feet,	
120	—	30
130	—	8

and at 140 fathoms, the two veins are so confused at their point of contact, that neither the quantity nor nature of the heave can be ascertained." At Dolcoath mine (situated on or near the junction of the granite and slate, not far from Camborne) there is an instance of a similar nature; but with the additional interesting circumstance, that the vein which in one part of the mine intersects and heaves the other vein is itself, at another part, intersected by the same vein without experiencing any *heave*. This fact was first recorded by Mr. Fox†, from whose communication we copy the subjoined diagram.

Fig. 18.



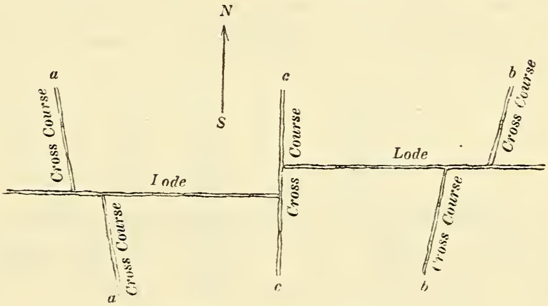
Dolcoath Mine. — (Bird's-eye view.)

* The miners make a distinction between *cross-courses* and *flucans*, and geologists have followed their example; but there are, in fact, no points of difference sufficiently important to justify such a proceeding; for a vein which, in one spot, is entirely composed of clay, at no great distance often becomes quartzose, the *flucan* passing by imperceptible shades into a *cross-course*. It is certainly right to note this difference of composition when it occurs, but it affords no grounds for instituting distinct classes: — nor indeed ought tin and copper lodes to be placed in different classes, for no such separation occurs in nature, the greater number of lodes containing ores of both these metals.

† Philos. Trans. 1830, p. 404.

2. *One vein intersects several veins which are parallel, or nearly so, with each other.* "In the Weeth Mine (near Camborne, in slate), two cross-courses are traversed by the same E. and W. lode; the direction of one (*a*) is 10° W. of N., of the other (*b*), about 10° E. of N: the former, is heaved three fathoms to the left; the latter, also three fathoms, but to the right hand. It is, moreover, particularly worthy of remark, that, whilst these two cross-courses are intersected by the lode, the latter is itself separated and heaved by a third cross-course (*c*): as exhibited in the next figure, taken from Mr. Carne's paper on Veins.

Fig. 19.



Weeth Mine. — (Ground Plan.)

In Ting Tang Mine, the main lode, bearing 10° S. of W., and the middle lode, bearing 21° S. of W., are both heaved to the right hand by the western flucan, which runs 15° W. of N.: and the amount of these heaves, in the respective veins, does not correspond at different depths; thus,

The main lode is heaved,		The middle lode
at 90 fathoms deep,	21 feet	21 feet
120	30	21
130	8	36;

and the same lodes, when traversed by the middle flucan, which bears 36° W. of N., exhibit similar irregularities."

3. *One vein is often traversed by several cross veins, and the intersected parts are not always heaved to the same distance.*

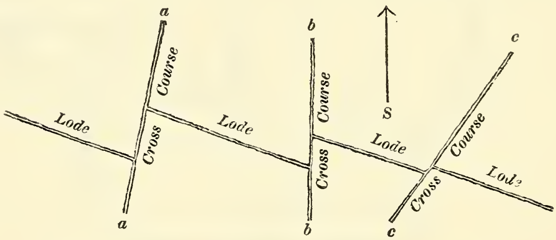
"For example, in Huel Friendship Mine (near Tavistock, Devon, situated in schist), as shown in the annexed plan, the lode bears 20° N. of W., dipping N. about 55°, and the

cross-course *a*,	10° E. of W.	W.	75°
b,	N. and S.	-	50°
c,	35° E. of N.	-	70°

These cross-courses all heave the lode towards the left hand; the first two towards the smaller, and the third towards the larger angle: but all of them have produced heaves of various extent. Thus,

The cross course	*a* has heaved the lode	21 fathoms,
- -	*b* - - -	17
- -	*c* - - -	3

Fig. 20.



Huel Friendship Mine. — (Ground Plan.)

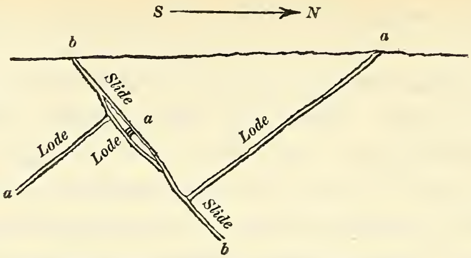
In this case all the heaves are in the same direction; but sometimes, as in Weeth Mine, recorded by Mr. Carne, the lode is heaved to the right by one cross-course, and to the left by another; and, in both, the heave is towards the larger angle." An illustration of the intersection of one vein by two flucans has already been given in fig. 17., taken from Huel Jewel mine. "The dotted lines denote the variable quantity of the dip at different depths: and it will be seen that both flucans heave the lode, the amount of the heave varying very much in the case of each flucan, but more especially in the eastern one, as indicated by the distance between the ends of the continuous lines on the opposite sides of the dotted lines. In the same plan, there are separations observable in the lode at *a* in the adit, the 10, 20, 30, and 40 fathoms levels; and at *b* in the eastern flucan at the adit: these are branches or parts of the vein separating from the main body. When they are productive of ores (and sometimes they are not inferior in this respect to the undivided part of the vein), they are denominated lodes, and not branches; size and the amount of ore being the only circumstances on which the distinction is founded: and when a lode thus separates into two parts, it is said to *take horse.* The form and extent of these portions of rock, or *horses,* depend on the disposition of the branches of the lode: sometimes the branches, like those of a river, reunite again, thus forming an insulated mass of rock; sometimes one branch terminates, and then the *horse* is connected at its base with the main mass of the rock, *or country,* having an angular and wedge-shaped form where situated between the branches of the vein; at other times the base of the *horse* abuts against a cross vein, as shown in the plan of Huel Jewel mine."

Such are a few of the appearances which veins exhibit, when they interfere with each other in their course or longitudinal direction, as brought to light by mining operations. We are almost entirely indebted to the same source for details concerning *throws,* or the apparent movements which veins experience by their coming into contact during their descent, in consequence of their dipping towards each other, or inclining in the same direction at different angles: the results of such an arrangement of veins are very various, and sometimes very complicated.

4. *Veins, underlying at various angles, often meet and intersect each other.* This sometimes happens with lodes, but is more common between lodes and slides, or flucans, which run somewhat parallel with the lodes.

"In South Huel Towan mine (near St. Agnes, in slate), the lode *a a a′* bears about E. and W., and has a mean dip of 55° S.; whilst the vein *b b* runs 20° S. of W., dipping about 50° N., at *b* it divides, and reunites at *b″*.

Fig. 21.

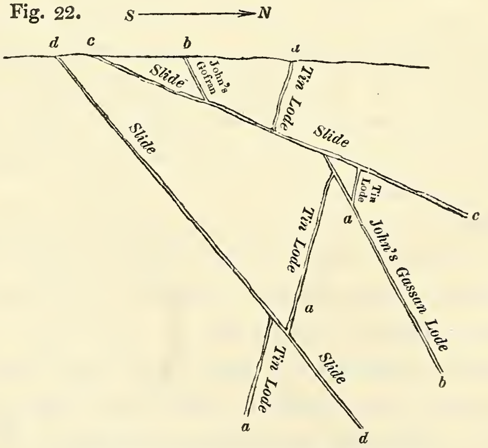


South Huel Towan. — (Transverse Section.)

The lode *a* is *thrown upwards* 25 fathoms; but between *b′* and *b″* the slide is divided, and between its branches *a′* was found, so nearly resembling the lode in composition that it is considered as a portion of the same."

" A very complicated example of *throws*, occurring in Huel Peever mine, has been recorded by Mr. John Williams *, in which one lode throws another, and are both in turn thrown by a slide. The tin lode *a a a a*, and John's gossan-lode *b b*, bear about 10° S. of W.; the dip of the former is about 70° S., and of the latter about 55° N.: the slides *c c* and *d d* run nearly parallel with the lodes; they are composed principally of clay, with a little friable quartz. The mine was worked in slate, near Redruth.

Fig. 22.



Huel Peever Mine. — (Transverse Section).

* Geol. Trans., vol. iv. p. 138.

John's gossan-lode	*b*	is thrown downwards by	*c*	18	fathoms.
The tin lode	*a*	- -		18	
- -	*a*	- upwards by	*b*	8	
- -	*a*	- -	*d*	9	feet.

Mr. Hawkins has mentioned a circumstance attending the *heaves* in this mine, which must not be omitted. "The middle segment of Huel Peever tin lode," he says, "was found to be much wider than the two others, and in a state of great disorder; and some fragments of the upper segment were carried off with the slide, or, more correctly speaking, strewed along the line of removal, to the distance of several feet. Traces of this disorder were likewise observed at the top of the lowest segment, occasioned by the gossan-lode." *

5. *Veins and elvan-courses often come into contact with each other; and the same phenomena result from this interference as from that of veins with each other.* Indeed, as already observed, *elvan-courses*, when metalliferous, are called by the miners lodes, as stated by Mr. Carne in the instances of Huel Unity and Rosewall-hill mines *; and they are justified in their view, since they exhibit the same appearances as veins: even Mr. Carne, although he has placed them in his *convenient* class of doubtful veins, says, that the evidence appears strongly in favour of their being true veins. †

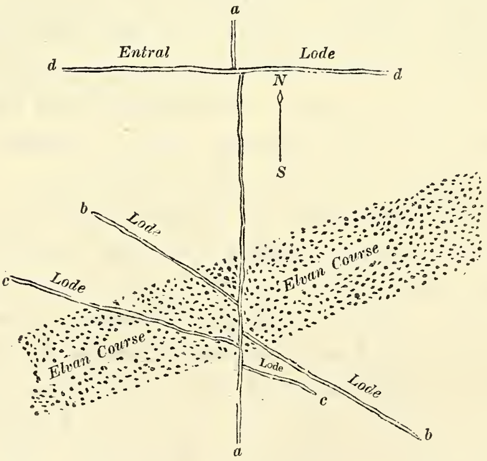
In general, elvan-courses are traversed by all veins, which commonly pass through without producing any alteration in the original position of the separated parts of the elvans; but many instances occur in which the phenomena of heaves are exhibited. In the fourth chapter, examples of heaves by quartz-veins and a flucan have been already described; and Mr. Hawkins, in his account of the lodes of Polgooth mine, states, that the elvan is at one place heaved by a slide, and in another it heaves the metalliferous veins. The vein B, he says, has been mistaken for a continuation of St. Martin's lode

* Geol. Trans. of Cornwall, vol. ii. p. 791. † Ibid. p. 83.

A, but its corresponding part must be looked for on the north wall of the *flucan*, or slide to the eastward of A.* This idea is certainly warranted by the theory of veins; but we are rather inclined to think that it is another instance of the incompatibility of fact and opinion, which is more conspicuous in this than in any other branch of the science.

" In Dolcoath mine," says Mr. Henwood, " the elvan comes into contact with several veins, by which it is intersected, whilst its own course remains undisturbed: and the appearances which result from these interferences cannot be explained on any assumption of motion. This elvan is twelve fathoms in breadth, of a granitic character, and is situated in slate, bearing 20° S. of W., and dipping about 34° N. Huel Bryant cross-course, *a a*, runs N. and S., and dips 87° W.; the lode *b b*, 30° N. of W., with a dip of 82° N.; the lode *c c*, 15° N. of W., dip 72° N.; and, lastly, the Entral lode bears E. and W., dipping 64° N.

Fig. 23.



Dolcoath Mine. — (Ground Plan.)

" The cross-course heaves the lode *b b* 9 feet to the left hand
- - - - *c c*, 30 - right;

* Geol. Trans. of Cornwall, vol. i. p. 152.

but it traverses the *elvan* without producing a like effect; showing that, if the veins have experienced motion, the containing rock has not participated therein."

6. *Veins are sometimes dislocated and heaved without the intervention of veins of any description.* "For example, in Balnoon mine (near St. Ives), the lode is entirely in granite, and is separated, both in length and depth, into regular detached portions, exhibiting all the phenomena of heaves and throws, without the usual accompaniments of intersecting veins, somewhat after the manner of the subjoined figure.

Fig. 24.

Balnoon Mine. — (Transverse Section.)

An instance of this kind has also been mentioned by Mr. Hawkins. "It is very remarkable," he says, "that at Ding Dong mine, in Madron, the tin lode is both heaved and started (thrown) by the cutters and clifts (seams or joints) of the granite through which it passes."*

In concluding this brief sketch of the Cornish veins, which has been divested as much as possible from all theoretical considerations, we would ask whether enough has not been advanced to show that the general idea of these veins is incorrect: and when we hereafter discuss the nature of their origin, it will be seen that our knowledge on this subject is as unsatisfactory as the descriptive details. From the leading facts which have been now brought together, we learn that veins, whether large or small, possess precisely the same characters: they are intimately connected with the containing rock by mineral transitions, and vary in composition as the nature of

* Geol. Trans. of Cornwall, vol. ii. p. 241.

the rock changes; they are not straight, but are curved both in their course and dip; their sides or walls are only distinct from the rock when the seams or joints are developed by decomposition, and are always partially confounded with the rock by a perfect intermixture or transition; they intersect each other both in length and depth, and in the larger veins those series which run in the same direction are generally affected by the others in a similar manner; but this is not invariably the case: their intersections are very frequently attended by alterations in the course of the disconnected veins, but the amounts of these apparent movements, in an extensive series, are very various, even in the case of a single intervening vein.

CHAPTER X.

GENERAL REMARKS ON THE PRIMARY ROCKS.

Recapitulation of the principal facts detailed in the preceding chapters. — Composition of the granitic rocks. — Each granitic formation characterised by peculiar series of granite — dependent on the nature of the accessory mineral. — This mineral subject to transitions — accompanied by corresponding changes in the series. — The different kinds of granitic rocks variously associated together, — their disposition among the primary schists — the nature of this connection. — Masses of granite whether large or small — insulated or interstratified with slates — are not of a different nature. — General remarks on the primary schists — their composition — modes of union — and frequent passage into each other. — No fixed order of succession. — Their nature illustrated by a series, commencing with micaceous gneiss. — The strata of each member of the schistose group composed of slaty and compact varieties — the latter pass into granitic rocks. — This group in each primary district characterised by the same minerals as the adjacent granite. — Remarks on the apparent fragmentary composition of some primary rocks, — and on the analogy between rock and mineral veins.

In the preceding chapters we have attempted, by detailed accounts of the primary rocks of Cornwall, and by copious extracts from the published descriptions of those of other countries, to concentrate our information on this department of the science, in order to prove that these rocks, wherever they occur, resemble each other in the following respects: they are composed of crystalline minerals, which, if not always the same, are the equivalents of and capable of mutual transitions into each other, and are subject to similar modes of aggregation; they also exhibit the same varieties of structure; and though in different districts, they present some diversity in their aspect; yet the manner in which the individuals of each formation are associated together, perfectly corresponds.

It may be observed that this is not disputed, and that the science of geology must not be studied within such narrow limits; its object being not only a knowledge of each group of rocks, but also the relation of these towards each other: thus, although the so called primary rocks constitute a distinct group, under whatever circumstances they occur, yet that they are not always referrible to the same geological epoch, inasmuch as they are not only connected with and graduate into the older groups of the secondary class, but are also similarly associated with those of the most recent of the same class, or even with the tertiary deposits.

From this statement it follows that the granitic groups are of different ages, a conclusion which in a great measure seems to depend on the nature of the passage of these rocks into those of the fossiliferous strata. The value of such a passage, as a criterion of the identity of rocks between which it occurs, will form one of the topics in the succeeding discussion: — indeed, it is now time to enter on an examination of the prevailing theory as applicable to the primary rocks; for the next step in the investigation, after having obtained a description of our subject, is to ascertain the true position and age of these rocks in reference to the other masses of which our planet is composed. But before entering on this consideration it will be desirable, by way of recapitulation, to review the leading points of the preceding descriptions, so as to obtain one general view of the primary rocks, divested, as much as possible, from all hypothesis.

Wherever the primary formations are extensively exposed to view, they are found to consist of granitic and schistose rocks: the former, for the most part, are composed of two or more crystalline minerals, which are generally aggregated in such distinct concretions that their nature can be easily ascertained, though, sometimes, the mixture is so fine that its constituents can only be detected by tracing their gradations into larger concretions: in the schistose rocks, this homogeneous appearance of the compound body does not only, as in the granitic, sometimes happen, but is their characteristic feature; and, in like manner, the composition of such schists can only be discovered when they can be followed up to layers or beds in which the elementary minerals are distinct, or when they contain irregular crystalline patches or veins into which they graduate. This natural mode of analysis will seldom fail when a series of these rocks is freely displayed.

The granular crystalline rocks of granitic groups almost universally contain felspar and quartz; to these is very frequently added mica, which is commonly conjoined with or its place altogether occupied by talc, hornblende, shorl, or some other mineral; and according to the nature of this accessory mineral, the composition of the different rocks composing these groups exhibits corresponding variations. Thus, the several kinds of shorl-rock in Cornwall, of hornblende rocks in Scotland, of talcose or magnesian rocks in Mont Blanc and in other parts of the Alps, of micaceous rocks in the Erzgebirge, and in other mountainous districts of the north of Europe, all appear to arise from the predominance, in certain parts of these granitic masses, of the respective characteristic mineral. And it not unfrequently happens, in extensive tracts, that this mineral does here and there pass into another; and in conformity to this change, the associated rocks undergo similar alterations. For example, in Cornwall, the mica of the common granite becomes talc, or shorl, whence result large beds of protogine and shorl-rock; in Ireland, the mica passes, here and there, into hornblende, producing syenite greenstone and other hornblende rocks; and in Scotland, and in other countries, similar transitions have been observed.

These granitic rocks, resulting from the combination of a small number of crystalline minerals variously aggregated, are associated together in several modes of arrangement. When viewed on a large scale, each district is characterised by one or more series of these rocks, disposed in distinct masses; which are divided, by the lines or seams of structure, into layers and subordinate concretions, all of which possess a certain degree of apparent regularity. Sometimes the various kinds of these rocks occupy separate layers; but, not unfrequently, several are found united, not only in the same layer, but even in an individual concretion; passing into each other, at some points, by the most imperceptible gradations, whilst at others they appear disunited by an open seam on the line of transition. Under these circumstances, they are disposed in the forms of courses, veins, or stripes, either parallel with the layers, or crossing them at various angles; either very large, so as traverse several layers, or small, and confined to one or more blocks or concretions of which the layer or bed is composed; or they constitute distinct nodules or spheroids of various sizes, which sometimes consist of concentric laminæ; but, more commonly, they occur in the state of spots and patches, very irregular both in size and shape. These different forms of granite are not only connected with the prevailing variety by mineral transitions, even within distinct concretions; but it sometimes happens, that the same porphyritic crystals belonging to the main mass are partly imbedded in the patches, veins, and courses of the associated granitic species.

Rocks of precisely the same composition as those just enumerated commonly occur on a smaller scale, in the crystalline slates adjacent to the large mass or group of granitic rocks; and under precisely the same circumstances of disposition in relation to the slates, as has just been stated to subsist between the subordinate and predominating varieties of the main mass of granite. For example, they occur in regular layers or beds, alternating with the primary strata, in Cornwall, Ireland, Germany, and elsewhere: and these granitic rocks are always of the same nature as those which form a component part of the adjoining mass of granite; and have been observed in Cornwall to pass frequently into the slate by mineral gradations; and not only so, but in addition to this, they sometimes are continuations of the same individual beds contained in the main granite. Again, they are not only disposed in the slate in regular beds, but also in courses, veins, patches, and nodules of divers forms and dimensions; all of which, occasionally, send out ramifications into the slate. These appearances are common in Cornwall, and have been frequently noticed in the crystalline slates of other countries, more particularly in gneiss and mica-slate; when they have been, from theoretical considerations, sometimes denominated granitic gneiss; at others, granite-veins. Let their nature, however, be what it may, there can be little doubt that all these phenomena are analogous to the detached granitic rocks in the slates of Cornwall.

It has also been shown, in the preceding pages, that the junction of the principal masses of granite and slate exhibits precisely the same appearances as those displayed by the union of the small insulated portions of granite with the schists in which they are contained: viz. they are often gradually assimilated to each other in composition; they not only mutually enter into the formation of the same layer or bed, but generally form integrant parts of the same concretion, in which case they are not disunited by the lines of structure, and are sometimes traversed by porphyritic crystals of felspar, as at Polmear Cove, on the north coast of Cornwall; they both contain angular and rounded portions of each other; and, lastly, the granite traverses the slate in the form of veins, which either run their course through both rocks, or proceed immediately from the granite, as elongations of the latter, with which they coalesce at the line of junction, or at no great distance therefrom within the mass of granite; and these veins, in their modes of connection with the slate, present a repetition of the same phenomena as at the junction of the main masses, even the granite of the vein and the schist partly containing the same porphyritic crystals, as at Bunawe (see chap. viii.); where the hornblende-crystals of the granite-veins "may be observed shooting far into the body of the schist, so as to render it often difficult to assign the limits of each rock; and in a less degree, the quartz and felspar exhibit the same appearance."

Thus we find, that the granite occurs in immense irregularly rounded masses, as in various parts of the British Isles, being insulated, at the surface, in the slate, and intimately connected therewith. These masses fluctuate greatly in their dimensions; even those of the Ocrynian range vary from fifteen miles to a few hundred feet in diameter: then again, from this size to a small nodule, every intermediate link is afforded by another series of granitic masses, which are known to be perfectly insulated in the schistose rocks; and which, we have just seen, have the same relations to the containing slates, as the large masses which have hitherto been detected in an insulated state only at the surface. Reasoning by analogy, it might be supposed, that all these masses of granite, whether large or small, possess the same constitution: the difference of dimensions being the only point, in which it can be positively asserted that they are not identical. As regards the layers or beds of granitic rocks, in the primary slates, experience has taught us that they possess the same characters; differing from each other only in the degree of their extent, but not in the nature of their associations with the schistose rocks: indeed, they can scarcely be considered in any other point of view; since, by the gradual passing of rounded into elongated masses, it appears to be demonstrated, that these forms are convertible into each other; and, therefore, are not indicative of different natures, being only modifications of the concretionary structure resulting from the various modes in which the integrant particles of the mass are arranged.

We cannot, indeed, draw any line of demarcation between the smaller and larger masses of granite, whether contained in the slate as rounded groups and patches, or interstratified therewith as elongated layers or beds: and since the beds of granite, alternating with slate near the junction of the main mass of the former rock, are proved to be of the same nature as the main mass, by their sometimes forming an integrant part of the layers of which the latter is composed, what discrimination can be made between such granitic beds and those which are interstratified with the gneiss and mica-slate of Norway and Sweden, and with the talc-schists of the Higher Alps, and similar formations? It is true, these are of much greater extent, and the smaller beds are generally more regularly disposed in their alternations with the schistose rocks; but this is no criterion on which to found a distinction, for if in those countries where the large masses of granite occur in central rounded patches, the smaller ones have the form of beds, possessing considerable uniformity with the containing strata, it is not surprising that where the main masses themselves appear to be stratified, that the lesser ones should exhibit the same characteristics in a higher degree. Indeed, the apparent perplexity of such a constitution of the primary districts is diminished, since we have learnt that even the granitic masses of Ireland and Cornwall are composed of an accumulated series of layers or beds, having a disposition to determinate bearings both in *strike* and dip; which is confirmed, if any farther evidence be necessary, by the fact just mentioned, that these beds sometimes extend far beyond the limits of the granite; and, when in the slate, bear the same relations thereto, as those granitic beds which seem to be wholly enveloped in the primary strata.

Some have argued from the arrangement of the granitic rocks in the northern part of Europe, that they are, in these cases, stratified; others are of opinion, that, like the trap and volcanic rocks, they have been intruded between the beds of slate, and consolidated in this position. We shall not, in this place, enter into an examination of either supposition: our only object by these remarks, and by the details in the preceding chapters, is to induce a conviction, if possible, that all the granitic masses, whatever may be their form or position among the slates, are of the same nature, as are likewise the individual rocks of which such granitic groups are composed.

It may perhaps be conceded, that all granitic rocks are analogous in composition, structure, and mode of formation; but that they belong to different epochs. But by so doing, various binary combinations, more particularly some of those which have been classed under the head of quartz-rock by Macculloch, and which are considered as stratified rocks, must be placed among the granitic, since they not only form an integrant part of the so called *unstratified* rocks, but, when in the slates, have the same relations thereto as the eurites, syenites, shorl-rock, porphyries, and other members of the granitic group. Farther evidence in favour of this arrangement will be immediately brought forward, under the head of the primary slates, the consideration of which will now occupy our attention.

Of all the members of the schistose group, gneiss is one of the most important: it is not, as once supposed, more intimately connected with granite by mineral transitions than other slates, nor is it necessarily always in sequence to this rock, though it commonly occurs in this position. It is formed of the same crystalline minerals as those which enter into the composition of the granitic rocks; though these commonly assume a different arrangement, being parallel to each other, whence arises the laminated or schistose structure, which is very often the only distinction between gneiss and granite. The component minerals of gneiss, like those of the granitic group, are united together in every possible proportion, and in granules of various sizes; and the resemblance of constitution is still greater, for each district of gneiss, and even different parts of the same district, possess a characteristic mineral; and this, by insensible gradations, passes into others: thus, hornblende, mica, and talc in Scotland and Norway, mutually graduate into each other, whence result different kinds of gneiss which alternate together. These continual fluctuations in the composition of the primary rocks are exceedingly interesting; at first sight they appear to be devoid of all order, but a careful examination has shown that this is not the case, several examples of which have been quoted from the works of Von Buch and Macculloch, in the fifth chapter, showing that the different series of gneiss do not follow each other abruptly, but are gradually connected by beds of the one occurring in the other, at first sparingly, and of a small size, and so increasing in number and dimensions, until one series disappears.

These general remarks on gneiss are equally applicable to every other member of the schistose group; the nature of their varieties, of course, depending on the composition of the schist. Mica-slate, according to most observers, consists of mica and quartz united in different proportions, and in diverse modes of aggregation; in some cases, Macculloch states, that it also contains felspar, especially when it is about to pass into gneiss, with which it is frequently associated. It appears to us very probable, that this combination is of more common occurrence, but that the felspar is not then distinct, being intimately blended with the quartz, giving rise to the extensive series of compounds, commonly called compact felspar, which exhibit every shade of character between perfect felspar and pure quartz; this opinion is founded on the fact, that all parts of mica-slate districts are not barren; and in these cases the slate is decomposed to a great depth, so that it is difficult to obtain an unaltered specimen : now mica, when combined alone with quartz, or indeed with felspar in a distinct granular compound like granite, does not appear to be susceptible of decomposition, and therefore could not produce such a soil; but when all these minerals are intimately blended, they readily disintegrate. On this conjecture, the reason why the binary compounds are better known is, that they are more durable, consequently more exposed to view, as tors and similar projecting masses, and more liable to be resorted to for specimens, on account of their more perfect condition. The same supposition equally applies to shorl, chlorite, and talc-schists; and it may be remarked, that in Cornwall such combinations do occur, the schists of this country abounding in or being characterised by compact felspar. The analogy is not perfect, nor indeed could any reasoning founded on this fact be conclusive, for each district throughout the world exhibits some peculiarity in the composition of its primary slates: so that it is possible that the general notion on this subject may be correct, but it is probable that felspar is more commonly present than is supposed, from the circumstance of its being distinctly developed in the mica-slates near gneiss; at a greater distance therefrom, it may be obscured, as often happens in other rocks, by its intimate union with their ingredients.

The composition of the primary slates of Cornwall, commonly called clay-slate or argillaceous schist, has been detailed at such length in the fourth chapter, and in such a connected point of view, that it is needless to offer any repetition: it may, however, be again remarked, that the two series which immediately succeed the granite, in the eastern and western part of the county, appear to have their equivalents in other countries; the latter series rarely, as in some parts of the Erzgebirge; the former more frequently, as in the southern part of the primary range of Ireland, in the Western Isles of Scotland, and in Norway, where it immediately succeeds or alternates with gneiss and mica-slate.

It was at one time supposed that all these primary slates succeeded each other in a certain order; and that either of them, from gneiss to clay-slate, might immediately repose on granite, but that the consecutive order of Germany, as described by Werner, was never subverted. This notion, however, is now exploded; principally through the labours of Dr. Macculloch, who taught us that these slates are arranged in Scotland in every possible sequence; and his statement has since been confirmed by observations made in other countries. Indeed, when we consider how few minerals enter into the composition of the primary slates, and the infinite but similar varieties of modes in which these are united, and the perpetual fluctuation or transition of these minerals into each other, it is not surprising that they are associated together in series of endless permutations. In order to illustrate this subject for the sake of the student, let us follow some of these changes, commencing with micaceous gneiss; that is, a compound of felspar, quartz, and mica. In the first place, according to the size of the constituents and their mode of arrangement, several species of lamellar, schistose, and compact (or granitic) gneiss, will alternate in beds of various dimensions: the granitic gneiss may lose its mica and become pegmatite (graphic granite), or a kind of eurite, according to the size of the grains; the former being large and crystalline, the latter small and intimately blended or actually combined, passing into granular or massive compact felspar-schists: or the same granitic gneiss may lose its felspar, and graduate into *griesen*, in which the minerals are distinct; and this again into an uniform compact quartz-rock or *avanturine;* and lastly, by the total disappearance of the mica, into a pure quartz-rock: or the granitic gneiss may be deprived of its quartz, when another kind of eurite would result. The more fissile species of gneiss exhibit similar variations, but the species thus produced have not been distinguished with the same minute details, except in one or two instances; viz. when the felspar is wanting, or when all the component parts, or the felspar and quartz alone, are united into an uniform and homogeneous texture: the varieties proceeding from the former condition are called mica-slate; from the latter, clay-slate. Such are the leading changes which the simple case of micaceous gneiss, devoid of all accessory minerals, may undergo; and which may be arranged in many different orders, imparting to a district a great variety of aspects. Let us now suppose the mica, in some parts of the series, to pass into hornblende; many new compounds would then be produced which may alternate with part or the whole of those just enumerated: thus many species of compact or schistose syenite would be formed by the conjunction of all the minerals, or of compact and schistose greenstones by the loss of the quartz; or by the homogeneous mixture of the component parts, traps and basalts, of various appearances, according to the modes of aggregation. Again, the mica of the micaceous gneiss may pass into talc, or the hornblende of the hornblendic gneiss into diallage; each, perhaps, a magnesian variety of the mineral from which they have proceeded by transition: and, in either case, similarly constituted compounds as those just described, will be produced, as seen in the magnesian rocks associated with micaceous gneiss in Norway, or more extensively developed in the Alps, which have been well described by Brochant, and quoted at length in the fifth chapter.

Each of these distinct series of gneiss is capable of passing into various kinds of clay-slate, by the intimate combination of their constituents, into a homogeneous schist, when the characteristic mineral is no longer perceptible, in consequence either of its minute proportion or gradual and total absence.

Since, therefore, we find that all the primary schists do, by changes in their composition, and in the modes of mineral aggregation, mutually pass into each other, it is not surprising, as above observed, that these transitions should be confined to no determinate order: thus, mica-slate may succeed granite, and yet in its succeeding beds become gneiss by containing felspar; so also hornblende-schist or clay-slate may be similarly circumstanced, and yet graduate into mica-slate or gneiss; and, subsequently, any or all of these may alternate together in different series.

In examining, however, every series of the primary slates, some portions of each will be found to be very compact, exhibiting no trace of the schistose structure. These compact varieties are sometimes disposed in regular beds, alternating with the perfect slate; at other times, they occur as masses more or less irregular, completely enveloped in the slate, terminating here and there in protuberances or veins: all of these masses are closely connected with the containing slate, by gradually passing into each other; and sometimes, indeed, but less frequently, the massive variety encloses irregular portions of the schistose.

These two principal kinds of the schistose group possess the same external concretionary structure, so as often not to be distinguishable at first sight, until the internal structure be examined. It is in the massive kinds that the constituent minerals are more distinctly displayed; indeed, in some series, particularly those of Cornwall, they can only be detected in these, and even then they are not always to be discerned, except in minute portions or veins; and thus it is that these massive rocks experience transitions into granitic rocks, not to be distinguished from those which enter into the composition of the main masses of these rocks. In districts of gneiss, for instance, the micaceous variety occurs in thick laminæ, which, becoming tabular and massive, cannot at last be mineralogically separated from true granite; or, the hornblendic variety, in the same manner, becomes massive syenite or greenstone, perfectly resembling the corresponding members of the granitic groups: so likewise the peculiar slates of Cornwall, when massive, graduate into eurite, felspar-porphyry, shorl-rock, and other kinds, similar to those which occur in the insulated masses of granite: and, lastly, it is no uncommon occurrence for the granular and compact quartz-rocks into which the primary slates often pass, and with which they are constantly interstratified, to form an integrant part of granitic groups, alternating with the different kinds of the *unstratified* masses.

Thus we learn that the granitic rocks, interspersed among the primary slates, are intimately united therewith both in composition and structure; and the same holds good at the junction of the main bodies of these rocks, as has been detailed at some length in the seventh and eighth chapters: and, indeed, a similar union subsists between limestone and granite. At Glen Tilt, for example, its large grained crystalline texture gradually disappears as it approaches the granite, and it more resembles hornstone or compact felspar; it effervesces slowly with acids, and gives, on analysis, a large portion of silica: the same limestone passes into quartz-rock by the same excess of silica, and this quartz-rock frequently contains felspar, and sometimes exhibits all the constituents of granite, so as to resemble foliated gneiss, and even perfect granite; and a similar quartz-rock forms a part of the granite of the adjacent Grampians, as exhibited in the ridge of Grianan. The limestone of Tirey, one of the Western Isles of Scotland, passes in the same manner into the gneiss with which it alternates: it contains concretions of hornblende, which mineral abounds in the gneiss; but of all the component parts of the latter, quartz is most generally in union with the limestone, and is probably intimately combined therewith, on account of its great hardness: it contains lumps of granite, and is traversed by granite veins, so that its junction therewith is of the same character as that of Glen Tilt.

Intimate as the connection of the granitic and schistose rocks thus appears to be, there is yet another point of view in which their mutual relations are still more closely united. It has been stated that both the granitic and the schistose groups individually exhibit in each district, or in different parts of the same district, characteristic minerals, the nature of which seems to regulate the composition of the respective series: now this is not only the case, but the characteristic minerals, in adjacent masses of granite and slate, are commonly identical; so that a perfect knowledge of the mineral transitions in one, may assist us in comprehending the nature of those in the other. Several instances of this connection have been noticed in the preceding details, of which the following are the most perspicuous. In Cornwall, shorl is the characteristic accessory mineral of the granite, but it is not sufficiently abundant to modify the general appearance of this rock, being only partially developed, so as to give rise to occasional beds of granular and compact shorl-rock; which also occur in the adjoining schistose groups, but not extensively, for their shorl speedily passes into hornblende, actynolite, chlorite, and various obscure substances, perhaps of an intermediate nature: but by far the most prevailing mineral of the Cornish granite is felspar, which averages at least three quarters of the whole mass, either in a crystalline form or in that state called compact felspar, large beds of which frequently alternate with common granite. This compact felspar is of two kinds: the one massive and crystalline, the other also massive, but with a fine granular and somewhat earthy texture; the first predominates in the granite of the western, the second in that of the eastern districts. So likewise in the western schistose group, various felspar porphyries and similar rocks are interstratified with slates, having a basis of compact felspar; and in the eastern district, several species of eurite, analogous to those in the adjoining granite, are associated with slates which have bases of the same kind of earthy granular compact felspar. In the primary district of the eastern part of Ireland, the granite of the northern part is micaceous with a frequent predominance of quartz; and the adjacent schistose rocks are different kinds of mica-slate, passing into and alternating with quartz-rock: on the other hand, the granite of the western part is principally composed of felspar and mica, "the quartz, comparatively speaking, seldom appears, and the mica often passes into chlorite or hornblende, all of which are not unfrequently intimately united with the felspar into a homogeneous compound." The adjoining slates here, also, exhibit a similar change of characters, having an uniform texture, like the rock commonly called clay-slate; and passing into hornblende-rocks, with which and with quartz-rock they experience frequent alternations. The fine granular basis in this and in the granitic group may be owing to a blending together of the felspar and quartz, as in the eurites of Cornwall, and thence the quartz cannot be distinguished in the granite, though it is sometimes developed, as in the slate, in the form of beds of quartz-rock, by its predominance over the other minerals. In Scotland, we have seen that the characteristic mineral of the granite is hornblende, which, like the shorl of Cornwall, occasionally usurps the place of the mica altogether; quartz, also, is here, as in Ireland, the prevailing ingredient in certain places: and the surrounding schistose rocks not only alternate with quartz-rock, which is sometimes in beds of very considerable extent; but all these rocks contain hornblende in various proportions, and this mineral frequently gains the ascendancy over the other ingredients, or obtains to such a degree as to impart its characters, producing greenstones, traps, and other kinds of hornblende-rocks. The granite of Saxony is essentially micaceous: it contains, here and there, hornblende, as in Scotland, but it is not so prominent a feature; and it is succeeded by micaceous gneiss and mica-slate, which likewise possess some occasional beds of hornblende-rocks. The granite of Mont Blanc is characterised by talc; and the strata with which it is associated are felspathic talc-schist, common talc-schist, and talcose slate, and many species of serpentine, euphotide, and other magnesian rocks. Lastly, the same connection occurs in Corsica: the granite alternating with eurite and protogine, or talcose granite; and the gneiss and mica-slate adjacent thereto are interstratified with the same beds, and pass into talc-schist, stea-schist, serpentine, and analogous compounds.

Other instances of this relation between the granitic and schistose rocks might be adduced; and these might have been enlarged, not only by pointing out the connection which generally prevails in each district, but by relating the lesser or subordinate appearances of this kind which occur in many parts of the same district. Sufficient, however, has been brought forward to show that every primary country displays such an intimate bond of union between the granitic and schistose groups, both in the small masses of granite entirely contained in the slates, and in the main masses of these rocks, that no line of demarcation can be said to exist in nature between them, as laid down by our artificial systems.

Before we proceed to the enquiry whether these groups have been derived from distinct causes, operating at different epochs, there are two other points to which we must briefly allude: viz. the apparent fragmentary nature of some primary rocks; and the phenomena of veins.

Concerning the rounded or conglomerated, and the angular or brecciated appearance of these rocks, no repetition of details need be here given, as a connected description of them will be found in the sixth chapter: but it may be remarked, that both the conglomerates and breccias of this kind occur in the granitic as well as the schistose groups. So that, if these fragment-like rocks be derivative and detrital when interstratified with the primary slates, as is generally supposed; they must be of the same nature, when connected with the granitic rocks: and since their alternation with these slates, has been received as a confirmation of the derivative nature of the latter, it ought to apply with equal force to the granitic rocks which we are taught to regard as of igneous origin. If we are compelled to consider this as inadmissible, because it appears more probable that, in the case of granite and volcanic rocks, these fragment-like forms are modifications of the concretionary structure; then the same solution ought to be extended to those primary slates that are similarly circumstanced. We do not argue here for either mode of origin; our intention is only to state that analogous appearances occur both in the granitic and schistose groups, which also in every other respect resemble each other; and if this be a correct conclusion from the facts recorded in the preceding chapters, the conglomerated and brecciated structures of the rocks of either group would seem to demand one and the same explanation.

Nor need any recapitulation be offered concerning veins, as these are separately described in the last chapter: but, it may be observed, that the granite-veins and elvan-courses, though treated of in other chapters, exhibit precisely the same phenomena. All these kinds of veins traverse both granite and slate, or are contained in either; they intersect many layers of rocks, or are confined to one layer, or, indeed, to an individual concretion, according to the size and position of the veins. So that granite-veins, and elvan-courses, only differ from each other in size; just as small mineral veins differ from those which are of considerable extent, and metalliferous: — the latter and elvan-courses commonly continue for so great a distance, that they have been supposed not to terminate, to have an indefinite length; but this is not matter of fact, for it is well known that both kinds frequently do terminate, at one or both ends, in minute strings which gradually disappear, even when the courses and veins are of no inconsiderable extent; thus, the quartz metalliferous veins, at Mousehole, St. Just, and, indeed, on all the shore of the Land's End district, are thus circumstanced; and the elvan-courses of Cape Cornwall and Mousehole terminate imperceptibly, the latter at one, and the former at both extremities.

Both the granitic and mineral veins of Cornwall gradually pass into the rocks which they traverse; and both present the same appearances of heaves, slides, and similar phenomena commonly referred to motion, when veins of the same or of a different class interfere with each other.

Having now concluded our general sketch of the primary formations, in which it has been attempted to show that the rocks of Cornwall are analogous to those of other granitic countries, in composition, structure, arrangement, and modes of association, we now proceed to the only remaining consideration concerning them; viz. the nature of their origin. Hitherto our subject has been descriptive; but, at the next step, it will become speculative; since a notion of the origin of these rocks can only be arrived at by deductions from facts: the conclusions thus formed, must, of course, be subject to frequent revisions, as we progressively obtain a more enlarged knowledge of Nature by the accumulated experience of successive observers. In the following chapters it is proposed to put the prevailing theory concerning the origin of the primary rocks, to the test of the facts which have been collected together in the preceding details: we shall, therefore, endeavour, in this discussion, to substantiate our objections to this theory, by appealing step by step to these details, and by numerous references to the labours of various geologists; and though we should fail in this object, yet we trust that the diligence exercised in order to arrive at the truth, will prove that the objections, though groundless, have not been hastily nor frivolously advanced.

We must not, however, terminate this description of the primary rocks, without making some allusion to the porphyries and zircon-syenites in the vicinity of Christiania, which have been described by Von Buch as overlying transition slate which contains organic remains. It appears to us, after a careful consideration of the details in the translation of this geologist's work on Norway, that this position of the crystalline rock is not clearly and satisfactorily demonstrated. The same remark may also be applied to the mass of syenite which is said by Macculloch to rest on fossiliferous limestone in the island of Skye. But even admitting the observations to be correct in both instances, these granitic rocks must be then referred, not to the primary formations, but must be considered as analogous to the eruptions of pyroxenic porphyry at Predazzo. On this view of the subject, these rocks would have the same relations to the primary, that the trap of Scotland has to the hornblendic varieties of granite associated with gneiss, mica-slate, and other crystalline schists: — their position and mode of connection with the strata denote them to be eruptive rocks; and although they resemble in composition some kinds of granite, their geological relations are very different from those which have been described in the preceding pages as belonging to the primary formations.

CHAPTER XI.

A SKETCH OF THE PREVAILING THEORY CONCERNING THE NATURE OF THE PRIMARY ROCKS.

Two classes of the primary rocks — the stratified and unstratified — the former of aqueous, the latter of igneous origin. — The whole Earth originally igneous — the granitic rocks the result of its secular refrigeration. — Igneous rocks of three kinds — granitic — trappean — and volcanic. — Granite a rock of all ages. — The crystalline strata associated with granite also belong to various epochs — supposed to be altered or metamorphic rocks. — The determination of the precise age of an individual mass of granite. — De Beaumont's theory concerning the relative ages of mountain-chains — not generally received.—Granite protruded in a solid as well as in a fluid state. — The prevailing theory a modification of that of Hutton — appears to be objectionable. — Lyell's statement of this theory abridged. — The nature of the objections about to be advanced — and the order in which they are proposed to be discussed.

Following the plan adopted in the preceding chapters, of endeavouring to make this work interesting even to those who are not professed geologists, it is now proposed to give a brief sketch of the prevailing theory concerning the nature and origin of the primary rocks. And, indeed, such a mode of proceeding may, perhaps, meet the approbation of the most experienced, as it will place the succeeding discussion on a more tangible basis, and diminish the chance of any misapprehension.

According to the most generally received opinion, the primary rocks are divided into two grand groups or classes, the stratified and the unstratified: the former comprising various kinds of gneiss, mica-slate, and other schistose rocks; the latter, all the granitic and massive rocks commonly associated with the former. These groups are supposed to have had very different origins; the one being of aqueous, the other of igneous formation. Thus it is presumed that the stratified rocks have been produced from the accumulated débris or detritus of older rocks, transported and arranged by the action of water after the same manner as beds of sand, clay, and calcareous substances, now actually forming in lakes, rivers, and the ocean: whilst the origin of the unstratified rocks, on the other hand, is attributed to the agency of an internal fire, which, according to various physical evidences, appears to exist in the centre of the earth; and to hold there an undisputed sway, converting all matter within its influence into a state of fluidity.

Some modern geologists, like Leibnitz and others of old, carry back their speculations to a period when the whole earth was, as they suppose, one element of liquid fire; and are of opinion that the granitic rocks have resulted from the cooling and consolidation of this ignited mass; that this refrigeration has been gradual, and is still in progress, whereby the crust or solid shell of the Earth is continually augmenting in thickness.

Now, if this conclusion be correct, and the data from which it has been deduced render it not improbable, the whole mass of granite is made up of successive or concentric layers, each of which is referrible to a distinct period of time. This second refrigeration, however, although progressive, is not supposed to have been always uniform in its operation, the melted mass having been, from some unknown causes, subject to periodical disturbances, by which it has burst through the incumbent solid rocks, and been protruded in various forms, according to the peculiar circumstances of the catastrophe. These forms, infinitely varied as they are, when we descend to minute distinctions, may be arranged under three heads: first, those that have resulted from fused masses which have not reached the surface of the earth; secondly, those that have been poured out at or near the surface, but at the same time exposed to a great superincumbent pressure; lastly, those derived from the fused mass whilst in free communication with the surface, either under water or in the atmosphere.

The first division comprises the different kinds of granitic rocks; the second, the traps and porphyries; the third, the various ejecta of volcanos.

On this view of the subject, it is evident that all kinds of igneous rocks may have been produced at different periods, and are still actually forming. This theory is supported by the fact, that trap and volcanic rocks are associated with deposits which decidedly belong to distinct epochs: but the evidence in the case of granite is not so decisive; and it therefore requires to be stated more in detail. The strata with which granite is intimately connected, in the form of veins and dykes, are generally more or less crystalline; and in some cases, so much so that they cannot be mineralogically distinguished from the granitic rocks; they are free from organic remains; in short, what are commonly called primary rocks. In some instances, these rocks are more ancient than the oldest fossiliferous strata, because the latter are composed of the detritus of the former: it is, however, contended by some, that this is no proof that the existence of animated beings commenced with the present fossiliferous strata, since these primary slates themselves may have been originally sedimentary rocks which once contained the remains of animals still more ancient than those which have been hitherto discovered. The obliteration of all traces of these creatures, according to the theory, has been occasioned by these strata having been in contact with granite, in a state of igneous fusion, for a period of considerable duration: this elevated temperature, however, was not sufficient to melt the strata, for they still retain their original structure; but to impart such a freedom of motion to their constituent particles, as to enable them to assume a crystalline structure on the refrigeration of the mass.

Now, according to these views, primary strata, not to be distinguished from those which are older than the secondary rocks, could be produced from any group of the secondary or tertiary formation, with which the protruded igneous granite might be brought into contact. The theory requires these periodical metamorphoses, and its supporters assert that nature exhibits such primary strata, not only associated with the greywacké, carboniferous, oolitic, and cretaceous groups, but actually passing into these stratified rocks, which were formerly supposed to be of more recent origins.

Granite is, therefore, now considered as a rock of all ages; inasmuch as the central igneous mass may be at any period injected among the superincumbent deposits: it remains to be stated how its precise age is to be ascertained. This point cannot be so easily determined as might be conceived on the first propounding of this subject; for granite in the vicinity of chalk, may be more ancient than that in connection with the oldest fossiliferous strata; because, in the latter case, the catastrophe by which the granite was raised, in a state of fusion, might not have been adequate to the propulsion of the mass beyond the limits of these deposits. How, then, is this point to be ascertained? The relative position of the strata is supposed to answer this indication: for, their inclination being attributed to the elevation of the granitic mass, by which the strata were broken through and tilted up at various angles, it is presumed to follow, that, if we find other stratified rocks resting thereon in a horizontal position, the period of the granitic protrusion must have been in the interval between the formation of the most recent of the inclined strata, and the deposition of the incumbent rocks. This interval, however, is frequently one of very considerable latitude, embracing several geological epochs: it is, therefore, only when the superimposed rock is the immediate successor of the newest upraised stratum, in a regularly consecutive series, that the age of the granite is most distinctly indicated; and even then, it can only afford an approximation to the truth, inasmuch as the precise lapse of time between these events has not been ascertained.

On this principle, M. Elie de Beaumont has recently endeavoured to determine the relative ages of the various mountain chains; and in the prosecution of this interesting enquiry, he has been led to conclude that all chains of the same date are parallel to each other. This new branch of geological speculations was, at first, almost generally received; but, on more mature consideration, many very formidable objections have been suggested. We shall have occasion to discuss this subject hereafter: it need only be now mentioned, that there appears to be but one opinion, — that these mountain chains have been elevated at different periods, by the operation of an internal igneous agency; but all are not agreed as to the manner in which this has taken place. M. Elie de Beaumont supposes these elevations to have been produced by sudden and violent convulsions; whilst, on the other hand, Conybeare, Lyell, and others, attribute them to a gradual, gentle, and protracted upheaving, continued without interuption during the whole period of the formation of the elevated strata.

According, therefore, to this modification of the theory, the granite must, in some instances, have been protruded in a solid state, subsequent to the alteration or metamorphosis of the adjacent strata; for it happens, that whilst the lowest strata are gneiss, clay-slate, or rocks analogous thereto, the upper, though equally inclined, and also adjacent to the granite, have not undergone any analogous change. Thus, Sedgwick and Murchison, in their observations on the isle of Arran*, say, "that the great dislocations of the secondary strata of this island were produced by the elevation of the granite, and that the upheaving forces must have been in action some time after the deposition and consolidation of the new red sandstone: that the granite could not have been in a fluid state, at the time of its elevation; for, had that been the case, it could never have risen into lofty mountains, and mural precipices, overhanging the secondary strata, without overflowing their broken edges, or penetrating their mass in the form of dykes." The same experienced geologists are also of opinion, that the Ord of Caithness† was likewise pro-

* Geol. Trans. vol. iii. p. 35. New Series. † Idem, p. 354.

truded in a sold form through the adjacent oolitic deposits; and, in the mechanical violence, indicated by the fractured and dislocated state of the stratified rock; and in the occurrence of a *breccia* composed of fragments both of granite and oolite, they find confirmation of their views.

In short, the prevailing geological theory is that of Hutton; modified indeed, and improved on, so as to adapt it to the numerous and important facts that have been collected since his day. One of the arguments which he triumphantly advanced against his opponents, the Wernerians, was founded, on the penetration of the stratified rocks by granitic veins, proceeding from the main mass of this rock; and likewise, on the occurrence of angular pieces of slate, enveloped in the granite; and other apparent signs of confusion and violence, which are generally found at the junction of the stratified and unstratified rocks. These facts are still esteemed, as affording an impregnable position for the Plutonic doctrine; and, though the followers of Werner have gradually submitted, yet the Huttonians are continually adding outworks to this strong-hold, in the hopes of increasing its security. This measure, however, has created more points that require to be protected; and, as has often been the case, this extended line of defence may ultimately cause its surrender. But to drop the simile, let us ask whether analogy has not been carried too far in this matter? It does not follow, because in volcanic formations we find one mass of lava penetrating the hollows and fissures of a former lava-stream, or of the adjacent stratified rocks; nor, because cracks and fissures in the volcanic cone are filled with sublimated matter; it does not follow, because such is the condition of these regions, that primary districts have been subject to similar catastrophes: and yet many geologists have not only referred the formation of granite-veins to an internal igneous agency, but also suppose that all the mineral and metalliferous veins which traverse the primary rocks, have had the same origin; fissures having been first formed, and subsequently filled from beneath by fusion or sublimation. But we must not anticipate the discussion, as it is only proposed at present to develope the various and most approved principles of the igneous theory.

Such an exposition, however consistent with the brevity here required, is not so easy a task, as at first sight it appears to be; but as it forms the basis of the proposed discussion, it is requisite that it should not only be free from misstatements, but also be made clear and intelligible to the reader. By way of recapitulation, therefore, we will call in the aid of Lyell's eloquent and perspicuous pen, by quoting such passages from his writings as will elucidate the nature of the leading doctrines of this theory.*

The class of rocks usually termed "primary," (a name which is not always applicable, since the formations so designated sometimes belong to different epochs), may, in general, be justly regarded as of higher antiquity than the oldest secondary groups, which we identify by organic remains, because there are rounded pebbles of granite, as well as gneiss, in the conglomerates of the oldest fossiliferous groups.

In order to explain to the reader the relation which we conceive the primary rocks to bear to the tertiary and secondary formations, it may be stated, that sedimentary rocks, containing organic remains, occupy a large part of the surface of our continents; but that here and there volcanic rocks occur, breaking through, alternating with, or covering the sedimentary deposits: the primary rocks, however, cannot be precisely assimilated to either of the preceding; they are often seen underlying the sedimentary, or breaking up to the surface in the central parts of mountain-chains, constituting some of the highest lands, and, at the same time, passing down and forming the inferior parts of the crust of the earth. These primary rocks are divisible into two groups: the one

* Principles of Geology, vol. iii. p. 352. et seq.

stratified, and produced from aqueous sediments, as gneiss, mica-schist, argillaceous schist, and some others; the second, or unstratified, which is supposed to have been formed by igneous action at great depths, whereas the volcanic rocks, although they also have arisen up from below, have cooled from a melted state upon or near to the surface. The unstratified primary, very commonly called Plutonic, often occur in large amorphous masses, from which small veins and dykes are sent off, which traverse the primary stratified rocks precisely in the same manner, in which lava is seen, in some places, to penetrate the secondary strata. Thus we find one set of granite-veins intersecting another; and granitiform porphyries intruding themselves into granite, like the volcanic dikes of Etna and Vesuvius, where they cut and shift each other, or pass through alternating beds of lava and tuff.

There is, however, a connecting link between the volcanic and Plutonic rocks, which makes this analogy much greater. The class of unstratified rocks, called trap, are compounds chiefly of felspar with hornblende or augite, which are associated with the fossiliferous rocks intersecting, overlying, and penetrating them as dikes, veins, beds, and amorphous masses. At first, geologists were divided in opinion, as to whether trap rocks were of igneous or aqueous origin; but now they are admitted to have been once in a state of fusion; it having been ascertained that the early comparison of trap to lava was imperfect, because a set of rocks, formed almost entirely under water, was contrasted with another which had cooled in the open air. Dr. Macculloch observes, "that it is a mere dispute about terms, to refuse to the ancient eruptions of trap the name of submarine volcanos; for they are such in every essential point, although they no longer eject fire and smoke." If a division, then, be attempted between the trappean and volcanic rocks, it must be made between different parts of the same volcano, — nay, even the same rock, which would be called *trap* where it fills a fissure, and has assumed a crystalline form on slow cooling, must be termed *lava* where it issues on the flanks of the mountain: and we must therefore consider the terms trap and volcanic as synonymous.

Again, the difficulty of distinguishing the volcanic from the Plutonic rocks is sufficiently great; for we must draw an arbitrary line between them,—there being an insensible passage from the most common forms of granite into trap, as detailed by Dr. Macculloch in his geological descriptions of Aberdeenshire, and other parts of Scotland. It would be easy to multiply examples to prove that the granitic and trap-rocks pass into each other, and are merely different forms which the same elements have assumed, according to the different circumstances under which they have consolidated from a state of fusion. The same lava which is porous where it has flowed over from the crater, and where it has cooled rapidly and under comparatively slight pressure, is compact and porphyritic in the dike. Now, these dikes are evidently the channels of communication between the crater and the volcanic foci below; so that we may suppose them to be continuous to the depth of several hundred fathoms, or perhaps two or three miles, or even more; and the fluid matter below, which cools and consolidates under so enormous a pressure, may be supposed to acquire a very distinct texture, and become granite.

For these reasons, it is probable that Plutonic rocks have originated in the nether parts of the earth's crust, as often as the volcanic have been generated at the surface. And we may also infer, that during each preceding period, whether tertiary or secondary, there have been granites and granitiform rocks generated, because we have already discovered the monuments of ancient volcanic eruptions at almost every period.

This supposition is corroborated by the observations of several geologists, that granite is not confined to one particular period, antecedent to the introduction of organic remains into our planet; but has been produced again and again, at successive eras, with the same characters, penetrating the stratified rocks in different regions, and not always associated with strata of the same age. Nor are organic remains always wanting in the formations invaded by granite, although their absence is more usual: granite so circumstanced has been detected by Von Buch in Norway, by Macculloch in Sky, and by Hugi and Elie de Beaumont in the Alps. In such examples, however, we can merely affirm that the granite is newer than the fossiliferous rock; but can form no conjecture as to the precise period of its origin. It is, indeed, very necessary to be on our guard against the inference that a granite is usually of about the same age as the group of strata into which it has intruded itself: for, in that case, we shall be inclined to assume rashly, that the granites found penetrating a more modern secondary rock, such as the lias for example, are much newer than those found invading strata older than the carboniferous series. The contrary may often be true, for the Plutonic rock, which was last in a melted state, may not have been forced up any where so near the surface, as to enter into the newer groups of strata; and it may have been injected into a part of the earth's crust formed exclusively of the older sedimentary formations.

It has been stated that the primary rocks are divided into two natural classes, the stratified and unstratified: the propriety of the term stratified is justified by a careful comparison of the rocks so designated, with strata known to result from aqueous deposition. If we examine, for example, gneiss, which consists of the same ingredients as granite, or mica-slate, we find that it is made up of a succession of beds, the planes of which are, to a certain extent, parallel to each other, but which frequently deviate from parallelism in a manner precisely analogous to that exhibited by sedimentary formations of all ages.

Another striking point of resemblance between the stratification of the crystalline formations, and that of the secondary and tertiary periods, is the alternations in each, of beds varying greatly in composition, colour, and thickness. For instance, gneiss alternates with layers of black hornblende-schist, or with granular quartz or limestone, and the interchange of these different strata may be repeated for an indefinite number of times. In like manner, mica-schist alternates with chlorite-schist and with granular limestone, in thin layers. As we observe, in the secondary and tertiary formations, strata of pure siliceous sand, alternating with micaceous sand and with layers of clay, so in the primary we have beds of pure quartz-rock alternating with mica-schist and clay-slate. As also, in the fossiliferous series, we meet with limestone alternating again and again with micaceous or argillaceous sand, so we find the gneiss and mica-schist alternating with pure and impure granular limestones. Reasoning, therefore, from the principle that like effects have like causes, the stratification of these primary rocks may be attributed to sedimentary deposition from a fluid.

But, if gneiss is a sedimentary rock, how comes it to pass that it frequently passes into granite, which is an igneous rock? The Huttonian hypothesis offers the following solution of this problem.—The materials, of which the gneiss is composed, were originally deposited from water in the usual form of aqueous strata, but these strata were subsequently altered by their proximity to granite, and to other Plutonic masses in a state of fusion, until they assumed a granitiform texture.

The geologist has been conducted step by step to this theory, by direct experiments on the fusion of rocks in the laboratory, and by observation of the changes in the composition and texture of stratified masses, as they approach or come in contact with igneous veins or dikes. Thus, the shale and limestone of Anglesea, when it approaches a dike of basalt at Plas Newydd is, according to Professor Henslow, gradually changed into porcelainous jasper and crystalline limestone. In the hardest part of the mass, the fossil shells are nearly obliterated: but the most extraordinary circumstance is the appearance in the shale of numerous crystals of analcime and garnet, which are distinctly confined to those portions of the rock affected by the basalt. This discovery is most interesting, because the garnets do not exist in the unaltered shale and limestone; and have, therefore, evidently been produced by heat, without effacing the marks of stratification: thus supporting the hypothesis that mica-slate, which abounds in garnets, is an altered sedimentary rock. Again, at Stirling Castle, the sandstone next the greenstone is indurated, and at the point of junction has assumed a texture approaching to hornstone. In the north of Ireland, the chalk next basaltic dikes is converted into a granular marble, and all traces of organic remains are effaced. And when these dikes pass through the coal measures, the shale is converted into flinty slate; and, in one instance, a bed of coal is reduced to cinder, for the space of nine feet on each side.

Let us now return to the stratified rocks next granite; and we shall find them, in such position, also presenting an appearance different from those parts of the strata more remote. Thus, schistose gneiss becomes massive, and not to be distinguished from granite, with the exception of lines of stratification, which, however, are sometimes very obscure. Mica-slate becomes gneiss under similar circumstances; and clay-slate passes into hornblende-schist.

This is not only the case with the primary stratified rocks, that is, those that are anterior to the greywacke and carboniferous groups, but the secondary beds of slate in the Alps, referrible to the age of the lias and oolite formations, are described by M. Hugi as having been converted into gneiss and mica-slate.

The Plutonic theory supposes that, in these cases, the heat communicated by the granitic mass, reduced the contiguous strata to semi-fusion; and that, on cooling slowly, the rock assumed a crystalline texture. The experiments of Gregory Watt prove that a rock need not be perfectly melted, in order that a re-arrangement of its component particles should take place, and that a more crystalline texture should ensue. It may, therefore, be easily supposed that all traces of shells, and other organic remains, may be destroyed, and that new chemical combinations may arise, without the mass being so fused as to wholly obliterate the lines of stratification.

According to these views, gneiss and mica-schist may be nothing more than micaceous and argillaceous sandstones altered by heat; and certainly, in their mode of stratification and lamination, they correspond most exactly. Granular quartz may have been derived from siliceous sandstone, compact quartz from the same: clay-slate may be altered shale, and shale appears to be clay which has been subjected to great pressure. Granular marble has probably originated in the form of ordinary limestone, having, in many instances, been replete with shells and corals now obliterated, while calcareous sands and marls have been changed into impure crystalline limestones. So that all the primary strata, so beautifully compact and crystalline as they now are, have once been in the state of ordinary mud, clay, marl, sand, gravel, and other deposits now forming by aqueous agency.

Before concluding this abridgment of Lyell's exposition of the igneous theory, as applicable to the primary rocks, it must not be omitted to mention, that he proposes the term *hypogene* as a substitute for that of *primary*,—a word implying the theory that granite and gneiss are both nether-formed rocks, or rocks which have not assumed their present form and structure at the surface: and to call the unstratified primary rocks *Plutonic*, and the stratified *metamorphic*, indicative of the changes which they are supposed to have undergone.

These terms are certainly in perfect accordance with the theory: and, if we could be assured that this theory is as securely established as are the fundamental principles of astronomy, they might be adopted without inconvenience: but geology has been, and is still, subject to a constant fluctuation of opinions; and has been already too much perplexed by a similar terminology; it is therefore desirable that, in future, the cultivators of this science should avoid, as much as possible, the introduction of names which have a theoretic signification. For this reason, we have taken the liberty of omitting the terms *hypogene* and *metamorphic*, in the following observations of Lyell on the relative age of the primary rocks.

"It it undoubtedly true," continues our author, "that we can rarely point out primary stratified or unstratified rocks, which can be proved to have been formed in any secondary or tertiary period. We can, in some instances, detect granites of posterior origin to certain secondary strata; and that secondary strata have sometimes been converted into gneiss, mica-slate, and others resembling primary. But examples of such phenomena are rare: and their rarity is quite consistent with the theory, that the primary rocks, both stratified and unstratified, have been always generated in equal quantities during periods of equal duration. We conceive that the granite and gneiss, formed more recently than the carboniferous era, are for the most part concealed; and those portions which are visible can rarely be shown, by geological evidence, to have originated during secondary periods."

"A considerable source of difficulty and misapprehension, in regard to the antiquity of the primary strata, may arise from the circumstance of their having been deposited at one period, and having assumed their crystalline texture at another. As the progress of decay and reproduction, by aqueous agency, is incessant on the surface of the continents and in the bed of the ocean, while the primary rocks are generated below, or are rising gradually from the volcanic foci, there must ever be a remodelling of the earth's surface in the time intermediate between the origin of each set of primary rocks and the protrusion of the same into the atmosphere or the ocean. The time required for so great a developement of subterranean elevatory movements, might well be protracted until a deposition of a series of sedimentary rocks, equal in extent to all our secondary and tertiary formations, had taken place. We conceive, therefore, that the relative age of the *visible* primary rocks, as compared to the unaltered sedimentary strata, must always be determined by the relation of two forces, — the power which uplifts the primary rocks, and that aqueous agency which degrades and renovates the earth's surface; or, in other words, it must depend on the quantity of aqueous action which takes place between two periods, that when the heated and melted rocks are cooled and consolidated in the nether regions, and that when the same emerge to the day."

"The principal effect of these volcanic operations in the nether regions, during the tertiary periods, or since the existing species began to flourish, has been, to heave up the surface of primary formations of an age anterior to the carboniferous. We imagine that the repetition of another series of movements of equal violence, might upraise rocks similar to the primary, produced during the secondary periods: and, if the same force should still continue to act, the next convulsions might bring up those belonging to the tertiary and recent epochs, by which time we imagine that nearly all the sedimentary strata, now in sight, would either have been destroyed by the action of water, or would have assumed the structure of the primary stratified rocks, or would have been melted down into granitic or volcanic rocks."

Having now given a general view of the prevailing theory concerning the primary rocks, and having endeavoured to elucidate the same by copious extracts from Lyell's "Principles of Geology," we proceed to point out those parts of the theory which appear to be objectionable; and to state the order in which it is proposed to conduct the discussion on which we are now about to enter.

It is laid down, as a fundamental principle of this theory, that the primary rocks consist of two distinct classes; not distinguished from each other for the sake of facilitating scientific descriptions, but severed by well-marked characters, and by natures diametrically opposite: the one having been formed from materials deposited and arranged by water; the other, by the action of an internal fire, at considerable depths below the surface. These conclusions are said to be founded on physical evidence,—on facts recorded by numerous observers in various parts of the world: and it may therefore appear to be an idle waste of time, an attempt of no little presumption, to make even a show of assaulting a position so strongly fortified. There is no intention of disputing the correctness of the facts, when such have been sufficiently investigated and faithfully described; but the evidence which these afford, may be sometimes disputed: for what is this physical evidence of which we so often hear, and to which theorists so frequently appeal? It is only a testimony recorded in hieroglyphics of an unknown character, and which may therefore admit of divers interpretations. In our attempts to decipher these characters, no solution can be admissible, unless it be applicable to all without exception. Now, the prevailing theory satisfactorily explains a great body of these facts, but it will be the object of the following pages to show that there are some phenomena which it does not appear to interpret in a clear and convincing manner. For instance, we are taught that gneiss, and other primary strata, which so nearly resemble the granitic rocks, especially at their junction with each other, are merely sedimentary deposits altered by the contact of granite in a state of fusion; and, that the condition of secondary strata next trap rocks, clearly indicates that such changes do take place under similar circumstances: but, after making every allowance for the comparison of small things with great, we shall strive to show that the cases compared are not analogous; that the evidence brought forward bears witness to changes produced by heat, but not to such changes as the primary strata are supposed to have undergone; viz. an assimilation of the aqueous to the igneous rocks, by the introduction of *additional elements* into the composition, of the former.

Lastly, the prevailing theory embraces igneous convulsions, as one of its leading principles; by which the stratified rocks are said to have been forced up from their original horizontal position, and inclined at various angles; by which they have been curved and contorted; and by which they have also been rent and fissured in various directions: thus affording space for the intrusion of igneous rocks, in the forms of veins or dykes, and for the formation of mineral and metallic veins; and also occasioning those faults and dislocations so common both in the stratified and unstratified rocks. To this doctrine, also, we cannot give our assent *in toto*. No one can deny, that volcanic fires have in former times occasioned, and still continue to produce, great mechanical alterations in the structure of the solid crust of our planet; but it does not appear to be satisfactorily demonstrated, that the inclination of the primary strata is attributable to this cause; nor, that the phenomena of granitic veins and dykes, and of metalliferous veins, are infallible indications of igneous convulsions.

These are grave and weighty points of dissent, as regards the stability of the Plutonic theory; and, if we can only succeed in the first instance, in giving plausible reasons for this difference of opinion, the objections ought surely to receive a candid and patient examination: they may be satisfactorily answered, or they may, perchance, prove knotty and stubborn opponents. In either case, it may be requisite to make appeals to nature by additional investigations: so that there is some satisfaction in thinking, that, in whichever way this discussion may terminate, by thus digging about and examining the ground of the radical doctrines of the science, the field of geology, like that of the departed husbandman in Bacon's fable, may be rendered more fertile and productive.

In conducting the proposed enquiry, it is intended to arrange it under the following heads:—

1. Are the primary schistose rocks stratified?

2. Have the primary schistose rocks been elevated into their present inclined positions by Plutonic agency?

3. Are the primary schistose rocks sedimentary deposits, altered by the contact of igneous rocks?

4. Do the primary rocks afford physical evidence that they have experienced fissures, dislocations, and other mechanical movements?

5. May not all the phenomena of the primary rocks, both stratified and unstratified, be satisfactorily explained on the supposition that these rocks are of contemporaneous origin?

CHAPTER XII.

ARE THE PRIMARY SCHISTOSE ROCKS STRATIFIED?

Definitions of the term stratum — not satisfactory — yet the basis of modern classification. — If primary slates be stratified, so are also the granitic rocks. — Primary slates and sedimentary deposits said to be analogous — proofs thereof advanced by Lyell. — This opinion of their common origin combated, for, according to this evidence, the igneous rocks are analogous to the stratified. — Involving a contradiction. — Granite said to be occasionally stratified. — Whence this contrariety of opinion? — Attributable to the structure of rocks — common to the individuals of every geological epoch — and every mode of origin. — Not dependent on successive depositions — but superinduced during consolidation. — This no new doctrine as regards igneous rocks — ought to be extended to aqueous deposits. — The structure of rocks a variety or mode of crystallisation. — This subject demands further investigation. — Conclusion. — Primary slates not stratified, in the usual acceptation of the word.

The question which forms the title of this Chapter may be regarded as very simple, and one that can be immediately answered in the affirmative. It appears, however, to be one of the most complicated in the science of geology: indeed, it may be stated now, as it was by Greenough fifteen years ago, in his excellent Geological Essays, " that the word *stratum* is so familiar to our ears, that it requires some degree of manliness to acknowledge ourselves ignorant of its meaning; and easy as it may seem to determine, whether a given mass be or be not stratified, there is, perhaps, in the whole range of geological investigations, no subject more pregnant with controversy." And, after adducing a mass of contradictory evidence on this subject, he concludes by asking many questions, and adds, " Let him who can answer these, rest assured that he has a distinct idea of stratification."

Now, though so many years have passed away since the President of the Geological Society solicited attention to this important topic, and though during this period the science has made unprecedented progress, yet the words *stratum*, *stratified*, and *stratification* are still in use, and have not, even at the present day, been satisfactorily defined.

Thus De la Beche *, in his explanation of terms employed in geology, says, " Although the word *stratum* should only be applied to a bed of rock, the upper and under surfaces of which are parallel planes; it is also employed to designate beds, the upper and under surfaces of which are irregular. Hence rocks are called stratified, even when the planes of the beds are not precisely parallel to each other."

So, Lyell † remarks, " When several rocks lie like the leaves of a book, one upon another, each individual forms a *stratum*."

Need it be observed that the term *stratum*, according to either of these explanations, is also applicable to the layers or parallel masses of the so-called igneous rocks; which implies a contradiction, for such rocks are generally said to be *unstratified*.

Macculloch ‡ has attempted to meet this difficulty, by extending its signification. " The term stratum or bed," he says, " carries its own definition with it; its extent, according to the prolongation of its great opposing planes, being generally far greater than its thickness: it is distinguished from masses of a similar shape, which occur among the unstratified rocks, by the nature of its origin; for the word stratification implies a cause, as well as a mode of form or disposition, and that cause is assumed, or proved, to consist in a deposition from water."

It is questionable, however, whether even this addition fairly meets the difficulty of the case: a definition ought to convey such an intelligible description of its subject, as to be easily recognised; but who, not even excepting the most accomplished geologist, can in all cases pronounce whether a

* Geological Manual, 8vo. p. 598.

† Principles of Geology, vol. iii. p. 81.

‡ System of Geology, vol. i. p. 67.

rock is of igneous or aqueous origin: the student, for whose assistance definitions are more peculiarly intended, can rarely make such a discrimination, and it must therefore be pronounced to be defective.

It is very true that it is well understood what is meant by the word *stratum*, though it is so difficult to embody the idea in correct language: but this very circumstance should induce us to suspect the propriety of employing such a term. So far, however, from this being the case, in defiance as it were of the indefinite nature of the term *stratum*, all rocks whatsoever are, according to the modern classification, divided into the *stratified* and *unstratified*.

If this statement be correct, it furnishes a curious subject for enquiry, how a system, apparently so illogical, could have been universally received? And it may diminish the surprise that otherwise might be felt, at our attempting to maintain so heterodox an opinion, as that the primary schistose rocks are not stratified. This, of course, can only be indirectly proved, since the term *stratum* has no precise meaning, by showing that if these rocks are stratified, then granite, porphyry, and similar rocks are likewise arranged in strata; but if the latter are unstratified, so are the former, because they do not possess any characters indicative of a distinct origin; both the granitic rocks and the primary slates being so intimately connected together in composition and structure, that the latter appear to be only *mechanical* modifications of the crystalline masses with which they are associated.

The opinion that gneiss and mica-slate are only micaceous and argillaceous sandstones, altered by the action of heat; and that quartz-rock and granular marbles are but siliceous sandstone and secondary limestone, which have undergone a similar change, is certainly in favour of the primary slates being stratified rocks; but, according to one version of the Plutonic theory, and the one least easily controverted, even some granites are altered stratified rocks; and, therefore, on this view, granite and its accompanying slates only differ from each other in the degree in which the supposed lines of stratification have escaped obliteration. But is this altered condition of the primary slates infallibly demonstrated? We think not: but this subject will be discussed under its appointed head: for the present we must confine our attention to the mechanical arguments derived from the form and structure of these rocks.

"The propriety of the term stratified, as applied to the primary slates," says Professor Lyell, "will not be questioned, when the rocks so designated are carefully compared with strata known to result from aqueous deposition."* He then proceeds to point out the analogies between these formations, and states, that "if either of the primary slates be examined, we find that it is made up of a succession of beds, the planes of which are, to a certain extent, parallel to each other, but which frequently deviate from parallelism in precisely the same manner as the sedimentary beds of all ages."

This resemblance between the structure of the primary and secondary slates is certainly correct; but it is no less true that the individual layers of which a mass of granite is composed, exhibit the same appearances as those of the stratified rocks. The parallelism of the layers or beds of granite, is a point which, it is presumed, will be readily conceded: indeed, it follows from the structure of this rock (as already described), that the beds may be either horizontal or perpendicular, when the granite is of the common type, or variously inclined, according to its nature and composition; and, what is of great moment, the direction or *strike* of these granitic beds is placed in a certain and determinate position, which in Cornwall is parallel with the most frequent course of the adjacent schistose rocks. This is no new statement; the same things have been remarked by many observers; but who, biassed perhaps by theoretical considerations, have not given them that weight which they appear to merit.

* Principles of Geology, vol. iii. p. 363.

The granite of Arran, like that of Devon and Cornwall, has the bedded appearance which, in detached parts, so much resembles stratification that it has not unfrequently been mistaken for it. "Nor is this great lamellar texture," observes Dr. Macculloch*, "peculiar to granite. In examining the Cuchullin hills in Skye, I have observed that the syenite and greenstone are bedded as it were in layers, either curved or straight, either horizontal or slightly inclined, resembling so much the disposition of granite beds that even an experienced eye would at a distance be deceived by them; and some kinds of porphyry also afford examples of a similar disposition."

Mr. Weaver, also, in his account of the east of Ireland†, concludes that the interior granite nucleus of this region is not stratified: but he adds, "that from repeated observations in several quarries and other denuded portions, I am led to infer, that the superficial parts or outskirts of this rock occasionally exhibit a disposition towards stratification."

After an enumeration of similar appearances, Macculloch ‡ has concluded with the following observations: — "In these cases, then, we have the stratified form as perfect as in the most regular beds of secondary rocks, produced by a species of crystallisation, a tendency to decided forms, with the laws and causes of which we are at least as well acquainted as we are with the laws that determine the figure of a quartz crystal. At present they are both equally inexplicable. There is no farther difficulty in conceiving that a rock may constitute a huge bed separable into horizontal laminæ, as regular as the strata of a mechanical deposit, than in conceiving that the island of Staffa is separable in columnar masses, or the rock of Devar into vertical laminæ. It is true that we have not yet produced any instance of continuous, horizontal, laminar concretions, which are incontrovertibly not mechanical; yet its existence implies no chemical impossibility. That which occurs on a small scale may occur on a large: the terms are

* Geol. Trans. vol. ii. p. 429.

† Idem, vol. v. p. 137.

‡ Idem, vol. ii. p. 428.

but comparative, and the works of nature are not to be limited by a measure taken from our own confined dimensions."

We might multiply authorities to show that the concretionary structure of granite, and of other so-called igneous rocks, "resembles strata so accurately, that a careful and unprejudiced eye must be the geologist's guide in distinguishing laminæ from strata, — a concretionary form from a real stratification." It might, however, be presumed, that a prejudiced eye is requisite to draw a distinction between things which appear to be perfectly identical.

We have seen, then, that the layers of granitic rocks are as regularly parallel as the primary strata, and the argument might be pushed even farther; for, as far as our experience goes, the layers of granite are sometimes more continuously regular than those of the slate, the latter being generally more curved, and not unfrequently contorted. It has also been stated, that granite has been observed to have a regular bearing, as recorded by Weaver in Ireland, De la Beche in Normandy, and Enys in Cornwall, a circumstance which cannot always be detected in the primary slates. For instance, "the stratification of gneiss," says Macculloch *, "is unquestionable, however difficult it may sometimes be to determine its order, or even to perceive its existence. In Scotland, where this rock abounds, the prevailing direction of the primary strata is between the N. E. and the N. N. E.; and while it conforms to this, when obvious, there are indications in the bearing of the coast, the positions of the hills, or the comparison of parts on a greater scale, which prove, that even where most obscure, it follows the same leading line: it is often, in fact, by this prevailing conformity *alone*, that the stratified disposition of gneiss is perceptible." By the same rule, the granite would probably be found to have claims to a stratified structure, if such indications had been sought after. And, if the granite should prove to have a particular

* System of Geology, vol. ii. p. 142.

bearing in Scotland, as in Cornwall, we should then learn that regular parallel lines, having the same *strike* as the schistose rocks, are more distinctly defined in the granite than in the gneiss.

But it has also been observed by Lyell, that "the analogy between the primary slates and the acknowledged sedimentary deposits, is not only shown by their beds being respectively parallel with each other, but also by their being subject to the same irregularities."

On the same grounds it may also be maintained, that the granitic rocks are also stratified; for, wherever a section of granite is exposed which is not in the direction of its bearing, that is, wherever the section is not confined to one and the same layer, the seams of the rock will be found to describe various irregular figures: sometimes the opposite lines are widened, sometimes contracted, and, not unfrequently, they terminate in a cuneiform mass by the union of these lines. And when these irregularities occur, the different layers are generally marked by a variation in the proportion and the mode of aggregation of the constituent parts. In some of these cases, it is true that most geologists would pronounce these layers to be veins; but, when layers of slate display precisely the same phenomenon, they are never so designated. A diagram illustrating these irregularities is given by Lyell; they appear in the Pyrenees, in a coarse argillaceous schist, and they are, as in the case of granite, accompanied by a difference in composition, part of the rock approaching in character to green and blue roofing slates, while another part is extremely quartzose, the whole mass passing downwards into mica-schist.

It has already been stated (in the chapter on the structure of the primary rocks), that whilst the common granite is either divided by open seams, or may be cloven into quadrangular blocks, the upper part of the quarries often exhibits various curved lines developed by partial decomposition, as at Carn-Gray near St. Austle, and at Kitt Hill near Callington.

This fact shows a tendency of the granitic mass to assume that spheroidal form which long exposure to the atmosphere produces on its individual blocks. Now these curved lines or seams, when viewed in a section, occasion some of the apparent irregularities observed in this rock: and when they meet with a granitic layer of different composition, they often abut against it, or continue their course in an altered direction, and thus they meet with and sometimes intersect other lines. In this manner, various complicated appearances are produced: but it must be remembered that these are not visible in the perfect rock, as is ascertained, not only at greater depths in the same rock, but when discontinued by coming into contact with a layer not so susceptible of disintegration; yet even in this, similar seams may be detected at or near the surface; which circumstances appear to show, that these lines depend on the manner in which the materials of the rock have been aggregated together.

In Cornwall, therefore, the granitic rocks are composed of layers, which, though frequently parallel, yet often exhibit irregularities, like those observed among the adjacent slates; and there is no reason to suppose that this granite is constituted differently from that of other countries. "The size of the concretions of granite and trap," says Macculloch, "if such they are to be considered, is often immense, and sometimes resembles strata. It is not often, however, that the laminar form is so perfect, for it will generally be found that the sides of a lamina are far from parallel, and that they frequently disappear in their progress, being irregularly entangled or implicated with others, not only of different sizes, but of various irregular forms."* In short, are the primary schistose rocks sometimes disposed in regular beds? So are the different kinds of granite. Are the beds of the former occasionally curved and contorted? So are also those of granite. Do regular schistose beds often abut against rocks

* System of Geology, vol. i. p. 166.

of a similar nature, but which are not fissile; and do these mutually interfere with each other, under every possible form and position? So, likewise, the regular layers of granite are similarly situated with respect to the more irregular concretions of the same rock. The president of the Geological Society, after having enumerated various appearances supposed to be characteristic of unstratified rocks, has recorded his conviction that the distinction is arbitrary and unsatisfactory. "Let us grant," says he, "all those properties attributed to the unstratified rocks: does the conclusion of the Huttonians follow from these premises? or, is there any one of these properties which may not equally be found among rocks that are stratified?" *

It must not, however, be omitted to mention, that Lyell attaches some importance to another character, as indicative of the primary slates being stratified. "The resemblance between these rocks and the sedimentary deposits," he observes, "is often carried farther; for, in the crystalline series, we find beds composed of a great number of layers placed diagonally, as we have shown to be the case in the crag and other formations."

This resemblance may be admitted, but it cannot be allowed as evidence of the stratification of the primary slates, unless this species of structure be clearly demonstrated to have proceeded from the action of water. This point is contended for by Lyell † at some length, but his arguments have failed to convince us, and we shall, therefore, in as few words as possible, state our objections.

These inclined layers dip at various angles from 30° to 45°: on the Suffolk coast they generally dip towards the south; but, in some instances, in opposite directions in the upper and under part of the same deposit, with the intervention of a horizontal layer. The Professor has supposed that these layers have been formed by deposition from water on inclined

* First Principles of Geology, p. 267.

† Principles of Geology, vol. iii. p. 176.

planes, and has likened this accumulation to the filling up of the furrows on the rippled surface of the sand hills, near Calais, with sand drifted by the wind. And he adds, "We must suppose that each thin seam was thrown down on a slope, and that it conformed itself to the side of the steep bank, just as we see the materials of a *talus* arrange themselves at the foot of a cliff, when they have been cast down successively from above." Then comes the deduction: "We think that we shall not strain analogy too far, if we suppose the same laws to govern the subaqueous and subaërial phenomena." To this we cannot assent, because, in the first place, the analogy does not appear to be correct. A *talus* certainly presents, in general, an inclined surface; but, as fresh materials fall, they are not equally spread over this surface, for they are carried on by the force of gravity to the lowest part of the inclined plane, where they accumulate to a greater extent than in the upper; so that, if we covered over, or otherwise marked, the surface between each precipitation, it would be found that the layers are not parallel, but fan-shaped; and the angle of the surface would constantly fluctuate during the accumulation. The condition, then, of such layers does not accord with those under consideration, and the case would be still more dissimilar under water, for it would require a current, or some moving power, to transport the materials of which the inclined laminæ are composed, to the slope; and, at an angle much less than that of 45° or even 30°, their heterogeneous constituents would be arranged according to their specific gravities. And it cannot be argued that the transported materials (the sand, slime, and shells) are so light, that the moving power might have acted very gently, for these layers sometimes consist of shingle, as at the lighthouse near Happisborough. Indeed, Lyell himself has subverted his own analogy; for, when speaking of the sand hills, he says, "When a gust of wind blew with sufficient force to drive along a cloud of sand, all the ridges were seen to be in motion at once, each encroaching on the furrow before it, and, in the course of a few minutes, filling the place which the furrows had occupied." Now this result shows, as we have stated, that the deposition would not take place in parallel layers on the inclined plane; otherwise the furrows would not have been filled up and obliterated, but the inclined side, if the analogy held good, would have changed its place, retaining, however, its original position. Besides, it might be enquired, how the first layer, on which all the succeeding ones are supposed to have been deposited, acquired its inclined position? And how, if these layers were formed by a current of water, do they occur in such a limited space, dipping in opposite directions?

These objections, perhaps, may not be deemed unanswerable: still it will probably be admitted, that this resemblance between the primary slates and the sedimentary formations, is not sufficient to prove that the former are stratified, and have had an aqueous origin: and this is all we wish to contend for at present. Although refusing to accede to the explanation advanced, yet we think that the fact itself of the peculiar arrangement in the laminæ of rocks is deserving of great attention, as it is analogous, on a small scale, to the disposition of extensive strata. The occurrence of such oblique layers among others differently placed, has been noticed in many rocks, by several observers, more particularly by Professor Jameson and Dr. Macculloch. The former has given some complicated instances, as occurring in the sandstones of East Lothian; and which he refers to the structure of this rock, and not to the mode of deposition*: and the same geologist mentions, in his Quarterly Journal, a similar arrangement in the laminæ of the trap-rocks at Edinburgh. Dr. Macculloch's remarks on the sandstone of Skye, written in the same year, have the same tendency. "The position of the beds of this rock is generally horizontal, never varying therefrom more than 5°. Each bed seems compounded of

* Memoirs of the Wernerian Society, vol. iii. p. 239.

two parts, the one a single horizontal lamina, and the other a series of inclined ones, or there is a regular alternation of a set of inclined laminæ with one horizontal one. This appearance is neither rare nor dubious; it is extremely well marked, and predominates throughout the whole range: and it is precisely similar to the disposition of the laminæ of the argillaceous schist in Isla. It hence follows that, if the fissile property of clay-slate is the result of some internal arrangement analogous to crystallisation, we are equally entitled to attribute the structure of the sandstone to the same cause." *

We are not, therefore, singular in refusing to allow this to be a mark of stratification, produced by a peculiar mode of deposition: indeed, if admitted, by the same rule, unstratified, volcanic, and trap-rocks become stratified, and also plutonic granite; since one of the beds of Arran, being divisible into laminæ, presents a similar appearance of unconformity of structure, when compared with the adjacent beds of this rock.

We now approach the concluding argument. "Another striking point of analogy between the stratification of the crystalline formations, and that of the secondary and tertiary periods, is the alternation in each of beds varying greatly in composition, colour, and thickness." "Reasoning, then," says Lyell, "from the principle that like effects have like causes, we attribute the stratification of gneiss, mica-schist, and other associated rocks, to sedimentary deposition from a fluid."

Surely no one who has carefully studied the primary rocks can have failed to observe that, though the rocks forming the schistose groups appear to alternate on a certain line, yet their beds do not exhibit that persistency of form so characteristic of sedimentary deposits; for if he should proceed either to the right or to the left of this line, with the view of

* Geol. Trans., vol. iii. p. 47.

tracing any particular bed, it will very frequently be found, within no considerable distance, to have passed into a different kind of rock. In fact, they are constantly changing their mineral character; and though on the large scale different kinds of gneiss, mica-slate, hornblende-schist, and clay-slate alternate with each other, yet the continuation of either, laterally, often assumes the appearance of all these rocks in detail. In this respect there certainly seems to be no great similarity between the crystalline and fossiliferous strata. But how does the case stand when we compare the primary slates with the granitic rocks?

If we traverse any considerable mass of granite which offers favourable opportunities for its examination, we find, as in the case of the primary slates, a certain succession of beds or layers, differing from each other in composition; and not unfrequently this series is repeated over again and again; that is, presenting precisely the same phenomenon which among the secondary rocks would be termed an alternation of strata. Thus, in crossing the central mass of granite due north from the neighbourhood of St. Austle, in Cornwall, a granitic rock first presents itself, which is composed of felspar, quartz, and shorl (a granitic shorl-rock); and this is varied by parallel layers, sometimes of considerable thickness, of granular or compact shorl-rock, consisting only of quartz and shorl; to these succeeds shorlaceous granite, a rock which contains shorl in addition to the common ingredients, felspar, quartz, and mica, and this rock again gives place to various kinds of true granite: still proceeding, we find the fine-grained granite pass into china-stone (in which the mica is replaced by talc), a rock fairly entitled to the name of protogine; and this is frequently traversed longitudinally by beds of shorl-rock, shorlaceous and common granite. In this manner the series is repeated, with greater or less regularity, in several portions of this great mass which have been exposed in the search after china-clay; and it is, therefore, reasonable to suppose, that the portions that are concealed from our view have a corresponding, though perhaps somewhat varied, constitution. Again, in the granite of the Land's End district, though the rocks assume a different character, yet here also occur various alternations of shorlaceous, common, porphyritic, pinitic, and other kinds of granite, with several kinds of felspar porphyry. Nor must it be omitted to mention, that this series, as well as that of every other granitic group in Cornwall, is augmented by the frequent presence of a rock which would be called by Macculloch quartz-rock; it is sometimes nearly pure quartz of different tints, sometimes it is more granular, and is combined with mica or with talc, which occur in every proportion, from the smallest quantity till they equal or exceed the quartz. Here, then, we have what is commonly considered as a stratified rock, entering into the series of unstratified formations: nor is this peculiar to Cornwall; it has been noticed in Ireland, in Scotland, and in other countries, as detailed in the third chapter. In Scotland, Macculloch* found the granite near Glen Tilt accompanied by, and in connection with, quartz-rock, along the whole ridge of Grianan, and in the elevated hills of Cairn na' Chlavhan and Connalach More: and he endeavours to account for this apparent anomaly, by attributing the presence of the quartz-rock in these situations to superficial and persistent masses, which escaped the common wreck of the strata by which the whole granite is supposed to have been once covered. He would not, however, have offered this solution, had he enjoyed the superior advantages which Cornwall affords for investigating this phenomenon: for there, the extended sections which are exhibited by the cliffs, and by mining operations, have taught us that the quartzose rocks not only pass into the adjacent varieties of granite by mineral gradations, but that they extend to great depths, and continue their course longitudinally, for a considerable distance.

* Geol. Trans., vol. iii. p. 296.

The granitic masses of Cornwall, therefore, are found to consist of alternating beds or layers of distinct rocks, after the same manner as the primary slates; and like these, also, some beds are very compact and massive, others are tabular and lamellar; but the latter do not pass into a perfect schistose structure, as in the granite of Arran. We have not such frequent opportunities of tracing these beds longitudinally as those of the slate groups; and it may be conceded, that the latter often run a longer course; but, it must also be admitted, that, in many instances, the granitic beds are more persistent than some of the primary strata.

But it may be objected, that Cornwall is but a small part of the world; and that it is, therefore, unfair to attach too much importance to a single example, which may prove an exception to the general rule. This argument is not started merely for the sake of extending the discussion, for it has been actually advanced by one who deservedly holds a distinguished rank among geologists, accompanied by a recommendation to visit other granitic countries. To argue on too narrow a basis has certainly been the besetting sin of our science; we have, therefore, no intention of disputing the correctness of such advice: but, in reply to the suggestion, that Cornwall may be an exception, we would venture to express an opinion, that the works of Nature are so consistent, and in such unity with each other, that they do not, like human laws and human productions, admit of exceptions, or similar contrivances for surmounting difficulties; and when our systems require them, it is a proof of their imperfection. If, for instance, we find the granite of Cornwall, however insignificant in extent when compared with that of the whole world, to have a certain structure (disclosed by advantages for examination, which no other known mass of granite possesses), are we to conclude that this is an exception, because at variance with our previous knowledge? Ought we not rather to suspect the correctness of our data, to ascertain, in the first place, whether there be in fact any discrepancy; and if not, to search for such an explanation as will offer a more satisfactory solution of all the phenomena?

But let us enquire, whether the granitic rocks of Cornwall do differ from those of other countries, as regards their structure? the point now under consideration.

In our sketch of the granitic rocks, in a former chapter, some examples will be found, which show that different kinds of granite do succeed each other, and assume, more or less, the appearance of regular beds. Such an arrangement is distinctly displayed at Zinnwald, in the Erzgebirge; but in this case, as in that of the Hartz, of the Alps, and of Norway, the granitic beds may be generally considered as belonging to the stratified rocks. If this view, however, be adopted, it is equally applicable to the granite of Cornwall and other countries; for all granitic groups are connected with schistose rocks in a similar manner, only differing from each other in the form of their respective masses: these being disposed sometimes in rounded insulated patches; sometimes in veins, dykes, layers, or beds; in short, exhibiting every variety of shape and size, both rounded and elongated masses of various forms and dimensions.

Although the examples adduced, and others which will readily suggest themselves, may not be considered so well defined as those of Cornwall, yet, it must be borne in mind, that the facilities for investigation also preponderate in favour of the latter locality. Can we, therefore, after what has been said, agree with Lyell,—that the alternation of beds, varying greatly in composition, colour, and thickness, is a proof that the primary slates are stratified?

In concluding, therefore, the examination of the analogies between the primary slates and the secondary and tertiary formations that have been adduced by Lyell, in order to prove that the former are stratified, and have been formed from aqueous depositions, we may, perhaps, be permitted to express a hope, that the objections which have been advanced are not without some weight; and that, if not altogether convincing, they may dispose geologists to enquire whether it be not possible that the primary strata may have had a different origin from those of the known sedimentary formations.

If it be decided that they are both stratified, then, if the foregoing remarks be correct, it follows that granite and the analogous rocks are also stratified. Such an opinion has been entertained; many geologists have asserted that it is partially stratified; and Humboldt, as quoted by Greenough *, has stated that he has discerned everywhere, in granite, strata which in all parts of the world have the same dip and direction. It would be unnecessary to enumerate the various authors who have recorded their opinions on each side of the question, whether granite is stratified; for this has already been ably done by Greenough: we shall therefore only add his conclusion on this topic. "Whence this contrariety of opinion? Are our senses at variance, or our judgments? The cause, I think, is obvious. Every one uses the word stratum, no one enquires its meaning; the remedy is as obvious — definition."

No one can dispute the accuracy of this reasoning: is it not, then, a remarkable circumstance that geologists should, from year to year, rest satisfied with the term stratum, and continue to use it unreservedly in the same indefinite manner, since the impropriety of so doing has been clearly demonstrated by a geologist of such acknowledged ability? That the case really still remains *in statu quo*, we have attempted to show in the preceding pages; and, farther, we have also endeavoured to argue that many of the leading characteristics of strata, such, for example, as have reference to their form and structure, are common to granite and other unstratified rocks.

On these grounds, therefore, we contend that if the primary slates are stratified, so are the granitic beds or layers of which the mass is composed; or, if granite is an unstratified rock,

* A Critical Examination of the First Principles of Geology, p. 7.

then are the primary slates of the same nature: that is, that the primary rocks are not divisible into stratified and unstratified; and that the separation which has been made on theoretical views, is not justified by the works of nature.

Let us, then, enquire whence this difference of opinion has originated. In the first place, we think that it will not be difficult to show that much of this perplexity is to be attributed to the structure of rocks; that is, to those lines or joints which are more or less common to all, when perfectly consolidated; but which are not always visible in the older rocks, until developed by a partial decomposition, and on that account are generally most conspicuous in quarries, cliffs, and other superficial sections. That an undue importance is not attached to this cause, may be inferred from the lengthened consideration given to it by Greenough, in his excellent essay on stratification.

In the chapter on the structure of the primary rocks, we have endeavoured to show that if the fissile texture of the slates be overlooked, that then these rocks would not be found to differ in structure from the compact greenstones, serpentines, porphyries, and similar unstratified or ignigenous rocks with which they are associated: and that the layers of these rocks, both schistose and compact, cannot in like manner be distinguished from those of true granite, since the principal joints of these rocks at their junction are commonly inclined at similar angles to the horizon. We will not recapitulate these details, but having referred to them, we will rather proceed to enquire whether the fossiliferous rocks have not a similar structure, and whether this is not sometimes perfectly independent of the operation of those causes by which the deposition of these rocks was produced.

In the transition or intermediate rocks, (such as occur on the northern and southern adjacent boundaries of Devon and Cornwall,) these lines of structure, crossing the beds in various directions, are as distinctly marked as in the slate in the immediate vicinity of the granite. It is not necessary to stop in this place to enquire how it is that these and the primary slates can seldom be distinguished from each other, except by some sparingly scattered and obscure organic remains, so insensibly do they pass into each other; nor to investigate the reason why the composition of these transition slates so seldom exhibits marks of their having originated from the detritus and debris of decomposed rocks: but must at present rest satisfied with the fact that both these orders of slates do possess a similar structure.

Mr. John Phillips, in his description of the schistose rocks between the rivers Lune and Wharfe, has frequently noticed this structure. Some difference of opinion may be entertained as to the precise geological era to which each of the three divisions of slate composing this district belongs: but this is, in the present question, of little consequence; it is only extending the subject of comparison from the primary to the carboniferous series. "Few subjects," says this intelligent geologist*, "are involved in greater difficulty than the question of the stratification of slate. We see this rock divisible into layers, and sometimes observe these layers alternately of a finer or coarser texture, appearances which in shale would be deemed very satisfactory evidence of the laminæ of deposition; but the generally vertical direction of the layers or planes of cleavage, and the numerous geometrically intersecting joints, leave much doubt in the case of slate. This difficulty is not lessened by the fact that, in many kinds of slate, there are really two cleavages or sets of laminæ, made evident by particular circumstances of weathering, though generally only one, which may be called the true cleavage, is practicable by blows. The oblique laminæ of false cleavage are generally regular and parallel to each other, and intersect the planes of true cleavage at certain angles, constant for the same quarry." Again, "from finding

* Geol. Trans., New Series, vol. iii. p. 16.

the surfaces of cleavage in the fissile granular slate marked with superabundant mica, and from observing that the organic remains were laid in the same parallels, it appeared that the laminæ of cleavage are indeed those of deposition. But these conclusions will hardly apply to the unmicaceous slate rocks; for, though near Horton, the large tables of slate have knots parallel to their surfaces, and are even separated by softer greenish layers, yet the level top of this series, as it lies exposed for miles under the limestone scar, must still make it hazardous to decide that the planes of cleavage and stratification are here coincident. And it is so often found in the slate of the middle division in the Lake district, that the planes of cleavage cross alternate layers of finer and coarser matter, that they may be considered as at right angles to the strata." "Next to the cleavage planes, the most constant of all the great joints are those which cross the cleavage nearly at right angles, in a vertical direction."

Now, compare this with what has been stated concerning the structure of the Cornish slates, in the sixth chapter, and it will be seen that these rocks are similarly constructed.

The beds of the greywacké and carboniferous series exhibit the same kind of structure; but the higher we ascend in the series, the greater is the difficulty, in many cases, in distinguishing the parallel layers from the effects of deposition. It has, however, also been noticed in the oolitic group, and is well known to characterise the gypsum formations. "At Hedington quarries, near Oxford, and at Anthony Hill, near Bath, the laminæ of the freestone are inconformable to the larger divisions. And, at Buckland Point, in the parish of Mells, Mr. Townsend found rhomboidal beds of oolite truncated, perfectly smooth in the superior and inferior surfaces, dipping at an angle of 40°, and confined between two horizontal beds of clay."*

But why multiply examples? A sufficient number of facts

* Greenough's Geological Essays, p. 13.

has surely been quoted to show that all rocks that are perfectly consolidated are, like the primary, traversed by lines, which cross each other at various angles, dividing the mass into forms more or less geometrical.

This we all admit, some may argue, but it furnishes weapons against the conclusion, in favour of which it has been advanced. Not so, we think: it establishes that the same structure is common to the primary and sedimentary rocks, but does not prove that the former are, therefore, stratified, in the usual acceptation of the term. Indeed, it rather leads us to doubt whether the parallel layers of the sedimentary rocks do owe their form to the mode in which they have been deposited. It cannot be questioned, that the concretionary surfaces are sometimes coincident with those of deposition, as is evident when each layer is separated by an uniform surface of shells, scales of mica, or other substances which have been arranged by water; and more especially, when the stratum only consists of one layer, succeeded by another of a different nature, but similarly circumstanced. These instances, however, are few compared to those in which the stratified rock is of considerable extent, nearly homogeneous throughout, and yet divided by layers in various directions. The principal lines which mark these layers are generally horizontal, or inclined at angles, which, in a great measure, correspond with those of the subjacent rock. Now these layers are supposed to mark the successive deposits from water, either in their original position, or tilted up by some power acting from beneath. But let us turn our attention to the actual state of such deposits, previous to their consolidation: can we detect any thing like what is called stratification, when the mass has been accumulated by the same agency operating under precisely the same conditions; that is, when the sedimentary mass consists throughout of the same materials, whether it be of clay, of sand, or of pebbles? Now such a mass, taken as a whole, may be evenly spread over an extensive space, having its upper and under surfaces parallel; or it may be level above, but convex beneath, owing to its having been formed in a basin-shaped hollow, or any other kind of concavity; or, on the other hand, it may be a simple cuneiform mass, thick at one end and tapering towards the other; or it may be thick in the middle, gradually diminishing towards both extremities, such as sand-banks present when within the reflux of the waves from the shore. In short, the *entire mass* may be of a regular form, or exhibit the most irregular and uncouth appearances, according to the circumstances under which it has been produced. Now we find similar masses in every geological era, presenting the same aspects; and, according to the best of our judgment, perfectly analogous: and such masses, when consolidated, are traversed by horizontal or inclined parallel joints, the intervening layers being often again divided by other intersecting planes. Are we then justified, in this case, to attribute either of these systems of joints (and why not one as well as another?) to an arrangement effected during their aqueous formation? Surely it must have forcibly struck every one who has carefully considered this subject, that all these lines have proceeded from some cause, operating subsequently to the deposition of the mass.

This statement does not depend altogether on the correctness of the arguments now advanced, and some may perceive objections to the analogy adduced, which have escaped our notice; it may, therefore, not be irrelevant to mention that the testaceous sand-banks, on the northern shore of Cornwall, furnish us with a practical illustration of this subject. Some of these banks are situated above high-water mark, resting on a bed of pebbles and shingle, into which they gradually pass, by the intermixture of the sand with the pebbles. The upper parts of these banks are homogeneous, and assume various irregular external forms, yet wherever this sand has been lapidified, it may be generally found consolidated into horizontal layers, sometimes not exceeding an inch or two in thickness. This occurrence in a rock so recently formed is certainly a case in point; and it may also be stated, that the siliceous sandstones, on the southern shore, present the same phenomenon. Thus we found "at the foot of Pendowa Cliffs, at the head of Gerrans Bay, near Veryan, a recent deposit of considerable thickness, the lowest part of which consists of pebbles similar to those of the adjacent shore, intermixed with sand, and some scattered fragments of slate. These pebbles gradually diminish in quantity upwards, till the deposit is composed entirely of sand, an intimate mixture of siliceous and argillaceous particles with minute scales of mica: this sand in its turn becomes more and more argillaceous, until it terminates in a bed of clay of considerable thickness. The under part of this deposit, for about ten or twelve feet in depth, including the pebbles and sand, is consolidated into horizontal layers of conglomerate and sandstone of a reddish brown colour. These layers average about nine inches in thickness, and have a very interesting appearance. The upper layers, being softest, have suffered most from the action of the elements, so that the lower ones successively extend farther from the cliff, forming an irregular flight of stairs: some of the layers, however, project, and are of sufficient tenacity to bear the weight of the body."*

In both these instances, the beds of pebbles and sand are evidently ancient beaches; and, like the existing ones, are placed on inclined slate, sloping down to the sea at a considerable angle. On these considerations, we think that it may be fairly concluded, that the lines marking the layers of the sedimentary rocks, though sometimes coincident with those of deposition, are not referrible to this cause, but depend on the mode in which the particles of these rocks have been aggregated during their consolidation.

This opinion is no new doctrine, though it is now proposed to extend it further, perhaps, than will be generally admitted. Most geologists, of late years, whenever they

* Cornish Geol. Trans., vol. iv. p. 271.

have observed appearances in granite, trap, porphyry, and similar rocks, which resemble those commonly attributed to stratification, have explained the apparent anomaly by assigning it to the concretionary structure of these rocks. Dr. Macculloch, in particular, has written much on this subject, a digest of which has been published in a connected form in his System of Geology*: and as his view of the subject has not been objected to, it may be therefore presumed that it is generally received. We must confess that it appears to us more specious than correct; and as a proof that the proposed discrimination is not a faithful sketch of nature, the student cannot, however diligent he be, reduce this precept into practice. The cause of this, if our deduction be not erroneous, is very evident; a distinction has been attempted, where none really exists: for all perfectly consolidated rocks possess a concretionary structure. It matters not whether the rock has had an igneous, aqueous, or any unknown origin; its particles were once disunited or mobile, either by the repulsive agency of caloric, by chemical solution, or suspension in water, by mechanical attrition, or by some other cause; subsequently, however, its particles have been brought within the sphere of their mutual attraction, by a reduction of temperature, by precipitation, by great pressure, by the percolation of water imparting the requisite degree of motion, or introducing extraneous matter, by which the separation of the particles is diminished or cemented; or, lastly, by any two or more of these compatible causes, which can operate in unison to effect the cohesion of the particles. We need not, therefore, enquire what has been the origin of a rock, before we determine whether it has a concretionary structure or not: since, in a mass of lava, of travertin, or of recent sandstone, each composed of lesser masses or concretions, more or less symmetrical, we learn that their structure is not exclusively dependent on any one particular mode or formation, for each individually, by placing the particles of

* Vol. i. p. 166.

these rocks under circumstances favourable to the exertion of the attraction of cohesion, effect the same object by different means.

This structure of rocks appears, then, to be a species of crystallisation: this idea has been already advanced by Professor Jameson and other geologists, but has been generally discountenanced, as a vague and unscientific proposition. But in what respects does it differ from crystallisation? In crystals, as in rocks, the integrant particles are combined and arranged by the attraction of cohesion into forms more or less geometrical. It is true, that rock concretions do not exhibit such symmetrical figures as the most perfect crystals; but this may in some measure be accounted for by the more complicated composition of these concretions: so that their forms are not the simple result of the aggregation of identical particles, but the balance of diverse powers, each tending to produce a different form. And it is also true, that we sometimes cannot detect any regular forms, though the mass is evidently concretionary, it being intersected in every direction by smooth planes, which give rise to irregular angular pieces: — yet, even in this case, we find an analogy among crystalline substances, whether simple as in salts, or compound as in the heterogeneous crystalline masses occurring in the cavities of veins; in all such cases, in short, as are attributed to a *confused* crystallisation; and this is no uncommon circumstance, for we find a hundred instances in which a substance is crystallised in an indeterminate mass, to one in which it is perfectly and regularly formed.

On this subject, however, it must be confessed, that we do not possess sufficient information to draw any positive inferences: but the case is strong enough to demand more attention than it has hitherto received. It opens an additional and almost unexplored region, which ought to be carefully examined, for it cannot fail to enlarge our knowledge of the earth's structure.

It would occupy too much space to particularise all the points that are elucidated by referring the lines or joints of rocks to their peculiar concretionary structure, and not to *stratification.* Indeed, occasions will frequently offer themselves, in the following pages, for this illustration: we shall, therefore, conclude the chapter, with remarking, that this view not only reconciles many of the incongruous opinions which have been advanced on this subject by the most eminent geologists; but it offers us an explanation of those parallel lines which often intersect formations, undoubtedly produced at different times; an occurrence that has caused no little perplexity. And lastly, it points out, how a difference of opinion has frequently existed on a subject so apparently simple, as whether a given rock is or is not stratified; for the term stratum has reference not only to the arrangement of rocks in parallel layers by deposition, but also to the tabular forms produced by joints or seams: and since this is only a variety of structure, common in a greater or less degree to all rocks, it clearly shows that it cannot be made a ground of distinction, much less the fundamental basis for a classification of rocks. The terms stratified and unstratified are, in many respects, synonymous with the two kinds of internal structure, — the massive or compact, and the schistose or fissile: the former predominating in granitic, trappean, and other rocks of this nature, commonly called igneous; the latter being more characteristic of the primary slates, and of the secondary and tertiary deposits, which are of aqueous origin. We have seen, that though each kind of internal structure respectively prevails in certain series of rocks, yet that neither is exclusively confined thereto: and thus it has happened, that some granitic or unstratified rocks have been pronounced to be stratified; and some members of the stratified have been called unstratified intrusive masses, though intimately blended with, and perfectly enveloped in, the former. We contend, therefore, that the various kinds of granitic and primary slates have been unnecessarily separated from each other; that these slates are not stratified, in the usual acceptation of the word, only differing from granite in the mode in which their component particles are aggregated together: and, finally, that although the primary slates in structure often resemble rocks of the fossiliferous groups, yet they are not detrital and sedimentary rocks, as we shall attempt to show in a succeeding chapter.

CHAPTER XIII.

HAVE THE PRIMARY SCHISTOSE ROCKS BEEN ELEVATED INTO THEIR PRESENT INCLINED POSITIONS BY PLUTONIC AGENCY?

Points proposed for discussion — the proofs of elevation — and the existence of an elevating power. — Position of tubulites in the strata of Shropshire. — Elevated strata of conglomerates — in Suffolk — at Helford Harbour — at Bad-na-Bae. — Inclined fan-shaped strata of Caithness — depositions on inclined planes — calcareous grit of Palagonia — shingle strata of Monte Calvo. — Inclined strata of vast extent. — The vertical strata of the Isle of Wight. — The nature of igneous elevations. — Igneous operations now in action — earthquakes — volcanos — *elevation-craters* not generally admitted. — Changes in the relative level of sea and land. — Temple of Serapis — coast of Chili — ancient beaches — subsidence of the Baltic — sea-cliffs and caves, inland — submarine forests. — Phenomena of trap-rocks — their position in the strata of Sicily — Skye — and Pembrokeshire. — Protrusion of granite — in a fluid and solid state — disputed — De Beaumont's Theory — Position of strata next granite — not always easily determined. — The bearings of primary strata not obvious — layers of these rocks threefold — continuous with those of granite. — Conclusions.

The fate of many geological speculations depends on the determination of the question which is about to engage our attention. For the sake of the general reader, it may be observed, that the prevalent opinion, at present, is, that the strata were originally horizontal; and that their departure from this position, indicates that they have been elevated by some subterranean power, such as the upheaving and protruding of granite, or some other ignigenous rock. A contrary opinion has been sometimes advocated: and it will be the object of this chapter to enquire, whether the evidence already collected will enable us to draw any satisfactory conclusion on this subject.

In our endeavours to dispute that the primary strata, now inclined, were originally horizontal, let it not be supposed that we wish to deny that strata have experienced dislocations, slides, or similar movements: this would be disputing the evidence of our senses. Our object is to examine the nature of the facts which have been adduced to prove that the inclination of the rocks, on the flanks of granitic mountains, has been produced by mechanical violence; to bring forward objections to the validity of this evidence; and to attempt to show that the inclination is in some cases delusive, and when real, as in the secondary and tertiary groups, may be sometimes accounted for, by the deposition of the sedimentary rocks on uneven surfaces.

That the primary slates have been tilted up at various angles, has been inferred from the analogy of the secondary and tertiary deposits, which are supposed to have undergone such elevations.

Admitting, for the sake of argument, that this analogy is correct, and that these rocks are all of aqueous origin, let us enquire whether it has been indisputably established, that the elevation of the sedimentary rocks has, in all cases, been effected by subsequent movements; or, if, in some instances, it has arisen from other causes, endeavour to ascertain on what grounds the latter are to be distinguished from the former.

It is to be presumed, that the evidence in favour of the elevation of the strata is very clear and satisfactory, since it has been so universally admitted. Among all the facts, however, brought forward in support of this opinion, none is more conclusive than the occurrence of tubulites in strata, placed at considerable angles to the horizon; since it is the known habit of these creatures to penetrate the ground, in a perpendicular direction. "The tubulites," says Mr. Aikin*, "in the clay-marl, interstratified with compact limestone, in Shropshire, are very thin, and scarcely an eighth of an inch

* Geol. Trans., vol. i. p. 206.

in diameter, with a length of twelve inches; and their position is perpendicular to the plane of the stratum, which, when this latter is at an angle of 40°, causes the coralline tubes to form an angle of 50°."

The author means, we presume, that the tubulites form an angle of 50° with the horizon in the *opposite* direction to that of the plane of the stratum. Another argument, to which great importance has been attached, is the position of the strata of conglomerates, which are sometimes inclined at considerable angles. It is asked, if these strata be in their original situation, how could the large rounded pebbles, of which they frequently consist, have remained in their places before the consolidation of the rock? Would they not, following the laws of gravity, have rolled down, and formed a *talus*, or heap, instead of regular strata? It is, therefore, contended, that they must have been formed in a horizontal position: but we think that in this case much may be said on the other side of the question.

These rocks occur in such different situations relatively to other strata, and under such varied circumstances, that it would be a long enquiry to examine into each distinct case: in some, we allow, the highly inclined layers could not have been deposited successively in such a position; whilst in others, it might be conceded by most persons that these beds of conglomerate have not undergone any movement since their formation. Now, in the former instances, can it be maintained that the inclined planes, traversing the conglomerate, are always referrible to the lines of horizontal stratification? In the last chapter we answered this in the negative, and the case now before us strengthens this decision.

Thus Lyell*, in describing the inclined layers which occur between horizontal ones in the crag formation of Suffolk, and which are disposed at angles of 30° and even 45°, says that "this diagonal arrangement of the layers, sometimes

* Principles of Geology, vol. iii. p. 174.

called *false* stratification, is not confined to deposits of fine sand and comminuted shells, for we find beds of shingle (pebbles of chalk flint, and of rolled pieces of white chalk) disposed in the same manner, as is seen in the section at the lighthouse near Happisborough." Consult this section, and it will be found that the entire mass (overlooking the lines or divisions by which it is traversed) presents a form very common on existing beaches; and, as the irregular and ancient deposits of sand on the Cornish shores acquire a subsequent arrangement into horizontal layers, so these beds of sand and of pebbles may have assumed the diagonal laminæ, the difference of the angle depending on the composition or some other modifying circumstance. This peculiar disposition of inclined layers between the planes of the strata is found in rocks of every geological era, and appears to depend (as stated in the last chapter) on the manner in which the attraction of cohesion has operated, and not on the mode of deposition.

We conjecture, therefore, that what occurs in these small banks of pebbles, holds good with the larger masses of conglomerate; that is, that the inclined planes which these exhibit are not always those of stratification, but are referrible to the concretionary structure, the result of the aggregation of the loose materials of which these rocks were once composed. Lest this opinion should be deemed to rest too much on bare assertion, we will refer to the page of Nature on this subject, and quote the following examples.

At Nare Point, Helford Harbour, in Cornwall, there is a mass of conglomerate* occupying the hollows and irregularities of the adjacent schistose rocks; the fragments and rolled pieces of which it is composed are of the same nature as the latter rocks; and it also exhibits the same structure, being traversed by systems of parallel lines, at elevated angles, but wanting the fissile texture of the parent slate. According to the received notion, the inclined planes of this conglomerate,

* Cornish Geol. Trans., vol. iv. p. 320.

parallel with those of the schistose strata, would be considered as elevated beds once horizontal, and which were placed in their present situation at the same time that the slate was upraised; but it must be observed that the position occupied by this conglomerate is precisely that in which beds of gravel and pebbles, now forming, are to be found at the foot of a system of elevated planes, where the detritus and debris of rocks exposed to the elements can accumulate. It may therefore be concluded that the parent slate, at the birth of the conglomerate, was not horizontal, but placed as it is at present, under circumstances favourable for the production of the latter: and that the inclined planes are not the result of stratification, but of structure; and it cannot be surprising that the concretions of this derivative rock resemble the slate, since it is composed of the same substance.

Let us now turn to another country, to Scotland. In their instructive and practical description of Caithness, Sedgwick and Murchison* have recorded that, "from beneath the whole series of stratified rocks, which dip towards the east, rises an enormous mass of conglomerate, occupying, for about half a mile, a lofty but singularly ruinous cliff, under a village called Bad-na-Bae. It is almost exclusively composed of fragments of granite, for which rock, without close examination, it might be easily mistaken; as, in its colour, mode of weathering, and its rude prismatic forms, derived from decomposition, it strikingly resembles a crystalline granitoid mass." "This conglomerate terminates against the granite near a cascade of the Ousedale rivulet, which tumbles from the height of about a hundred feet into the sea. We here observed a somewhat startling phenomenon, which we do not, however, believe to be of unfrequent occurrence. A part of the conglomerate is so perfectly granitoid, that it is not easy to determine where the depository mass ends, and the crystalline rock begins."

* Geol. Trans., vol. iii. p. 139. (New Series).

In this case, also, we have another instance in which the structure of the conglomerate accounts for the lines or seams by which it is traversed, without referring them to stratification. Here is an immense mass of detritus which has been derived from granite, and, not having been transported far from its source, still resembles granite in composition. When consolidated, this rock, as might be expected, being formed of the same ingredients, assumes the same structure as granite. The learned authors, indeed, do not state that the mass is traversed by parallel lines, as is commonly the case with granite, but if made up of an aggregation of prismatic concretions, it may be inferred, without any great assumption, that the structure, in this respect, also resembles granite: and then we have, in this case, perpendicular layers of strata of conglomerate. Many geologists, indeed, have described similar phenomena in various parts of the Alps, and of other countries, and have attributed them to the elevation of horizontal strata. But may it not be fairly doubted, in the instance before us, that the layers of conglomerate have been so raised, since this apparent movement can be accounted for without having recourse to the agency of such tremendous convulsions, as would be required to produce this effect? There are, besides, other objections, one of which may now be mentioned; viz., that if horizontal strata have been so upraised, all of them ought to exhibit the same angle of inclination. In Caithness this does not hold good: thus, the old red conglomerate, in the narrow valley which separates the Scarabins from the Maiden Paps, dips at 45° towards the great northern plain; but at Schmian, which is farther removed from the central quartz-rock, the dip of the same is not more than 10° or 12°. So that it is arranged fan-shaped; and the upper sandstone and calcareous schists follow the same order, being inclined, at various angles, from 30° to 40° till they become nearly horizontal.*

* Geol. Trans., vol. iii. p. 138. (New Series.)

This example shows that it is not probable that these fan-shaped strata were deposited in horizontal layers: but if they were formed on inclined planes (the lowest being at the greatest angle, and each deposit becoming more horizontal by a greater accumulation at the lower part, according to the laws of gravity), then there would be no occasion to call in the aid of any movement, to account for the position of these and similar formations.

But can sedimentary depositions take place on inclined planes, in beds parallel thereto? are they not always accumulated in horizontal layers, exhibiting truncated edges next the fundamental inclined surface? This is supposed to be the mode of formation in most cases; but it is admitted, even by the advocates of an original horizontality, that it is very possible for the former condition to have occasionally obtained. Thus, as already stated, Lyell endeavours to account for the inclined laminæ between horizontal layers in the crag, and in various schistose rocks. And the same author, when contemplating the irregularly curved and diagonal structure of the calcareous grit on each side of the pass near Palagonia, in Sicily, remarks, "that it is somewhat difficult to conceive in what manner this arrangement of the layers was occasioned; but we may, perhaps, suppose it to have arisen from the throwing down of calcareous sand and volcanic matter, upon steep slanting banks at the bottom of the sea; in which case they might have accumulated, at various angles, of between 30° and 50°, as may be frequently seen in the sections of volcanic cones in Ischia and elsewhere. The denuding power of the waves may then have cut off the upper portion of these banks, so that nearly horizontal layers may have been superimposed unconformably; after which, another bank may have been formed in a similar manner as the first."* It is not necessary to pause here, to comment on the probability of such a mode of formation; it is suffi-

* Principles of Geology, vol. iii. p. 72.

cient, for our present purpose, that the possibility of strata deriving their inclined position from some other cause than that of forcible elevation is admitted. There is another example, however, recorded in the excellent work of this geologist, which must not be omitted, as it bears with great weight on the point now under consideration; viz., the inclined beds of stratified shingles which are situated between the base of Monte Calvo and the sea, in the vicinity of Nice. "Uniform and continuous as these strata appear, on a general view, in the ravine of Magnan, we discover, if we attempt to trace any one of them for some distance, that they thin out, and are wedge-shaped. We believe that they were thrown down originally upon a steep slanting bank or talus, which advanced gradually from Monte Calvo to the sea. The distance between these points is about nine miles; so that the accumulation of superimposed strata would be a great many miles in thickness, if they were placed horizontally upon one another. The aggregate thickness, in any one place, cannot be proved to amount to a thousand feet; although it may, perhaps, be much greater. But it may never exceed three or four thousand feet; whereas, if we did not suppose that the beds were originally deposited, in an inclined position, we should be forced to imagine that a sea, many miles in depth, had been filled up by horizontal strata of pebbles, thrown down one upon another."*

Thus we learn, that strata of no inconsiderable extent may be deposited on inclined planes; and that they may be individually wedge-shaped, or gradually thickening from the highest to the lowest portions: and on what evidence, then, are we to assert, that the inclined fan-shaped strata of Caithness, and all others similarly circumstanced, have not been formed in the same way?

We are also further instructed by the last example, the tertiary pebble-beds of Nice, to look for another cause of

* Principles of Geology, vol. iii. p. 169.

their inclination than that of igneous elevation, to which such phenomena have been referred in almost every instance. But why make this exception? Because it would be otherwise necessary to imagine horizontal strata of pebbles many miles in thickness. But why be daunted at the contemplation of a single member of the tertiary group, only a few miles in depth, after having viewed, unmoved, the supposed elevation of not only the total mass of tertiary rocks, but also of the whole series of secondary rocks, which, subjected to the same measurement, would indicate an incomparably greater thickness? Yet these are, in every portion of the globe, found resting on each other in an inclined position, for very many leagues from the mountainous ridges of granite: and, surely, if it be no easy matter to conceive strata of tertiary gravel, less than nine miles in thickness, it must require a much greater scope of the fancy to conceive such enormous masses of primary slates and secondary rocks to have been elevated from a horizontal position by the protrusion of granite. Some idea may be formed of the great depths from which such horizontal strata must have been raised, since Humboldt has observed a single rock, clay-slate, dipping N.W., at an angle of 70°, for forty-five successive miles. We quote from Greenough's "Essay," who adds, "Can it be imagined, that these strata were once horizontal, and consequently fifteen leagues thick; or that, falling, they found a chasm large enough to receive them?"* So Macculloch says, "the thickness of the erected edges of a series of strata, is the measure of the original depth before elevation: and it has been computed by Playfair, from observations of Pallas in the north of Europe, that we probably by this means gain access to sixty-one miles in depth, or nearly a sixty-fifth part of the radius of the globe."† But it must, in fairness, be observed, that he thus concludes this topic:—"According to the rules above laid down for com-

* Geological Essays, p. 53. † System of Geology, vol. i. p. 96.

puting the original depth of such strata, we may be easily deceived. If it be imagined, for instance, that a horizontal series was elevated at different points in succession, so as to preserve such a consecutive disposition, as might aptly be represented by the teeth of a saw, it is plain that a very small number of original strata would give rise to a great series of inclined ones; and that we might form a very false conclusion respecting the real nature of such a series." Though we shall object hereafter to this explanation, yet it must be admitted, that when the repeated succession of a limited number of strata, in consecutive order, occurs, their total thickness must not be measured by the addition of the dimensions of each stratum individually. But after every allowance for such cases, the volume of primary slates and fossiliferous rocks, which immediately follow each other, and are inclined in the same direction, must still be very enormous. Indeed, an actual calculation of their thickness would perhaps furnish us with a datum, that would render the supposed elevation more improbable than that of the inclined gravel beds in the vicinity of Nice.

Is it then to be concluded that strata have in no instance been removed from their original position? Certainly not; though at the same time it is very possible to account for many appearances, which have been supposed to afford well-marked examples of movement: the vertical layers of conglomerates have already been considered; and the perpendicular strata of unconsolidated sand and marl at Alum Bay, in the Isle of Wight, may now be alluded to. It has been stated, that sedimentary deposits may be formed on surfaces inclined at considerable angles, and as the limits of this mode of production have not been ascertained, we are not prepared to say that it cannot, under particular circumstances, extend to the perpendicular: besides, it is not requisite that such deposits should be of great extent, as they may have originally constituted only the descending portions of considerable curves, the upper portions of which have been removed by aqueous denudation. But, at the same time, it must be confessed that this is a mere attempt to put aside a difficulty which a better knowlege of geological phenomena may hereafter satisfactorily explain : in the interim, however, it must equally remain a stumbling-block for the Plutonic theory ; for although the central fire is fully adequate to such an elevation, yet the *how* and the *when*, in this case, are not clearly indicated.

In thus contending that many, and indeed far the greater number of, inclined strata are in their original position ; it is not disputed that the convulsions, produced by the internal fire, may have occasioned many dislocations and displacements.

Before proceeding, however, farther in the examination of this question, it is time to enquire into the nature of this igneous agency, as regards its power of effecting an elevation of the strata.

The phenomena of active volcanos afford presumptive evidence that there is an internal fire, as supposed by the prevailing theory, by the expansive force of which the rocks, being in a state of igneous fusion, are either injected from time to time amongst the strata, or are poured out through the fractured strata on the surface of the earth, either under water, or in contact with the atmosphere. And it has been inferred, since some of the lavas so formed cannot be distinguished from greenstone, and other rocks, which are most intimately and inseparably connected with granite, that, therefore, the latter rock is of igneous origin, and that the strata have been ruptured and tilted up by its protrusion in a melted or solid state.

In the first place, as regards the analogy of primary hornblende rocks and lavas, we think that their perfect resemblance, both in composition and structure, does not indisputably prove that they were formed in the same manner. It is true that lava may be converted into greenstone, and the latter into the former, by duly regulating the mode of cooling, from a state of fusion: this shows that they may have had the same origin, but at the same time it renders it possible that the lavas have been derived from the fusion of primary rocks at a great depth; a conjecture not so very improbable, since fragments of the older rocks are sometimes projected from the craters of volcanos. We know that many mineral substances have been and can be produced by aqueous as well as igneous agency: but if we only knew of one mode of formation, it might be surmised that like substances were similarly derived; the inference, however, would not be infallible. Most persons, for instance, if they found within a rock a mass of solid native copper, would conclude that it had been melted by fire, because they know that this metal can be so formed by art, but are not, in general, aware of any other mode of production. The conclusion, however, might not be correct; for by the precipitation of a solution of sulphate of copper, either by the direct application of the poles of a galvanic battery, or by the electrical action resulting from the immersion of iron, sheets, nodules, or even pieces of copper of no inconsiderable size may be obtained; and sometimes so perfectly solid, when precipitated by iron, that they resemble the products of the furnace.

Besides, admitting that our planet was originally in a state of fusion, and that it is still undergoing refrigeration, only the external part or crust being as yet consolidated, it does not follow, although the lavas issue from the same central igneous mass as that from which the granitic rocks have been also derived, that the latter have, therefore, been protruded in like manner, because they may have resulted from the original consolidation of the earth.

It is necessary, however, in order to ascertain whether this be the case or not, to enquire into the respective positions of the granitic and volcanic rocks: and, proceeding from the known to the unknown, we must, in the first place, examine the phenomena of existing volcanos. It will not be necessary to enter into minute details on this subject; it will be sufficient for our purpose to remark, that the eruption of volcanos is usually preceded by earthquakes, occasioned, as is generally supposed, by the struggle of a highly expansive power, such as intensely heated vapours, to overcome the continuity of the incumbent rocks; and these convulsions are commonly terminated by the vapours finding vent, either through previous craters, or through fissures produced by their overcoming the resistance of the superimposed mass. These fissures are sometimes simple chasms or ravines, of greater or less extent, which are either superficial fractures, or communicate by one or more channels with the volcanic foci.

Sometimes gaseous fluids only escape through these vents, but more commonly they are accompanied by the discharge of ashes and other incoherent substances, which, falling around the fissure, form, by the accumulation of successive layers, a conical mountain, the summit of which is an open outlet or crater. These layers slope from the centre of the mountain on all sides, as is evident when the ejecta have periodically varied either in colour or composition, or when, in consequence of its submarine origin, they alternate with aqueous deposits. The same arrangement is also evident when the volcano has poured out lava in a state of fusion, as it also either partially or generally produces successive layers, reposing on each other, or alternating with various igneous products, according to the nature of the matter erupted. Currents of lava are not, however, always disposed in this regular manner: the convulsions to which these volcanic masses are subject, often occasion fissures of various dimensions, into which the lava flows, or is injected through channels connected with the central vent, and subsequently consolidating, it has the form of dykes and veins, intersecting the volcanic layers or strata in various directions.

Whilst volcanos continue in action, the cone increases, its inclined layers reposing on and gradually extending over the fundamental rocks, which remain in their original position.

Some geologists, indeed, are of opinion, that both extinct and active volcanos afford examples of the permanent elevation of the strata, since these sometimes dip on all sides from the centres of these igneous mountains. Others, however, refuse to acknowledge the existence of such craters of elevation; and this subject has occasioned several animated discussions at the meetings of the Geological Society of France; Montlosier, De Beaumont, and Dufrênoy maintaining, and Cordier and Prévost opposing, this opinion. Cordier, in particular, has expressed his dissent in very strong terms: — "La dénomination de *cratère de soulèvement* est aussi fausse et aussi vicieuse que l'hypothèse, qu'on a eu l'intention de qualifier par son moyen. En effet, cette hypothèse est gratuite; elle pose en fait l'existence et le renouvellement multiplié d'un phénomène qui est sans exemple, et qui d'ailleurs, par les forces prodigieuses et purement locales qu'il aurait exigées, ne serait en aucun rapport avec l'intensité et la nature des effets volcaniques authentiquement constatés." The same eminent philosopher, after having enumerated the various kinds of craters, states that their formation is accompanied by tremendous detonations, and thus concludes: —"La percée du sol n'en est pas moins un phénomène purement local, qui n'affecte, pour ainsi dire, qu'un point dans la masse du terrain traversé, qui opère sans soulèvement aucun de cette masse, qui s'effectue par une série de fentes très peu étendues, et dont les effets paraissent excessivement minimes quand le bruit a cessé."*

It is at present, therefore, undecided, whether strata have or have not been elevated into an inclined position by volcanic action; but it appears very probable that, when the highly expansive vapours connected with the volcanic force, cannot force their way through the incumbent strata, so as to cause an eruption, this power is not always exerted in vain; but, at each renewed effort, it raises up bodily not only large tracts

* Bulletin de la Société Géol. de France, tome ii. p. 399.

of land, but even whole continents. This opinion is supported by many records concerning volcanic countries, which indicate not only occasional elevations of land, but also similar depressions, as in the notable example of the temple of Serapis at Pozzuoli. The extensive elevation of the coast of Chili, at the time of the earthquake in 1822, is another fact of great importance, inasmuch as the same coast affords indications of a succession of such catastrophes, thus affording an explanation of the analogous elevated beaches and cliffs so common near the shores of many parts of Europe. It has been long observed, that the waters of the Baltic sea are retiring from the land in many parts of Sweden and Finland; indeed, it is the general persuasion in Sweden, that the land is slowly and insensibly rising; and Haussman, Von Buch, and other geologists who have examined the countries bordering on the Baltic, have advocated the same opinion. Lyell has taken a different view of this subject, attributing the gradual filling up of the Baltic to the accumulation of fluviatile and marine sediments; and has supported his conclusion by the citation of many weighty facts.* During the past year, Mr. Johnston has contributed an excellent paper on the elevation of the land of Scandinavia †, in which he admits that parts of the Baltic are silted up, and that the growth of ancient pines close to the sea, on the coast of Finland, and the similar position of the walls of the castle of Abo, prove that no sensible change has taken place in those spots for a long period; but he contends, that though this is decisive as to the permanence of the water's level, it in no degree weakens the positive evidence of a rise of the land in many parts of Scandinavia. Observations similar to those made by the Swedish philosophers, during the early part of the last century, "have been repeated at various intervals, and as late as the year 1821, under the joint direction of the Swedish Academy and the Russian Minister of Marine.

* Principles of Geology, vol. i. p. 228.

† Edin. New Philos. Journ., vol. xv. p. 34.

The result of these comparative admeasurements is, that, along the greater part of the Baltic, the mean height of the water appears to fall from three to five feet in a century, or about one foot for every twenty-five years. Adopting this fact," he observes, in another place, "we naturally enquire into its probable cause. Among the ordinary phenomena of volcanic action, we find nothing at all parallel to the case before us: they afford many examples of elevation, even to a great extent, but these are all the result of a single impulse, or of a succession of violent impulses applied within a short space of time." He concludes that we shall find in the secular refrigeration of the globe, a cause not only for the elevation of ancient mountain chains, but also for the gradual elevation of the land in Scandinavia; and he offers a very ingenious application of his hypothesis, which however our limits will not permit us to follow.

If we mistake not, the central or volcanic fire is generally supposed to have slowly and gradually upheaved the land above the level of the sea. The coast of Chili, however, shows that it has operated *per saltus*, by successive impulses, and not by a continued and equable action. The occurrence of caves high in the granitic cliffs of the Land's End, Cornwall, corresponding with those which are now at the level of the sea, confirms this fact, as does also the cave in the Monte Grifone, near Palermo, mentioned by Lyell *, and the inland cliffs of the Val di Noto, and of other places enumerated by the same author †, and which he admits prove distinct and successive elevations. Indeed, these appearances appear to demand this explanation; for, if the change of level were gradually effected, it might be expected that the power which was adequate to form a cavern, or cut down a cliff at a given level, would have continued its operation through the intermediate space, downto the present high-water mark. Whether these elevated ancient beaches, and the submarine

* Principles of Geology, vol. iii. p. 141. † Ibid. p. 110.

forests which invariably occur on our coasts, at or immediately beneath low-water mark, be attributable or not to the elevation or depression of the land by volcanic influence, one thing is certain, that there has been a repeated alteration in the relative level of sea and land, and that these changes have been accomplished without affecting the inclination of the strata.

Having considered some of the leading phenomena of the central fire, as indicated in volcanic districts, we now proceed to enquire whether the igneous rocks found in the fossiliferous strata exhibit the same appearances.

Basalt and other trap-rocks do not appear to have acted on the adjoining strata in a different manner. They are found overlying the strata of each geological epoch, in masses which are more or less regularly disposed; they intersect the strata in different directions, in the form of dykes, which are connected with masses of a similar nature, either at the surface or beneath, or descend to unknown depths; but, in all these cases, the sedimentary rocks are frequently found in their original position, exhibiting no marks of angular disturbance.

Thus, in Sicily, a country which is at present, and which appears to have been during the tertiary epoch, peculiarly liable to volcanic convulsions, the stratified rocks of this period do not present those inclinations and contortions which we are taught to attribute to igneous catastrophes. "The disturbance," says Lyell*, "which the newer pliocene strata have undergone in Sicily, subsequent to their deposition, differs greatly in different places; in general, however, the beds are nearly horizontal, and are not often highly inclined. The calcareous schists, on which part of the town of Lentini is built, is much *fractured*, and dip at an angle of 25° to the north-west. In some of the valleys in the neighbourhood, an anticlinal dip is seen, the beds on one side being inclined

* Principles of Geology, vol. iii. p. 73.

to the north-west, and on the other to the south-east." For what reason is this distinction made? is it not suggested rather on theoretical grounds, than by any distinct evidence? There does not appear to have been any necessity for this proceeding; for since the strata are in general nearly horizontal, that is, since they have suffered no angular displacement, why not suppose that they are all in their original position? For the same author has shown in many instances, even in the very case itself of the pass of Palagonia, that the materials of such strata may have been thrown down here and there upon steep slanting banks at the bottom of the sea, not only at an angle of 25° (equal to that of Lentini, above quoted), but at various angles between 30° and 50°. Why then attribute the inclination of some of these strata to violence, when the adjacent and continuous beds, extending over a considerable tract, are supposed to have been elevated several thousand feet without any disturbance?

Whilst considering these Sicilian deposits, it may be remarked, in passing, that, however easy it is to conceive that their present elevated position, relatively to that of the sea-level, has arisen either from an upheaving of the land, or a depression of the sea; yet, during the formation of the successive deposits, it is probable that the action of the power producing the change was not so simple as is generally supposed. Lyell, if we mistake not, has attributed the position of these tertiary rocks to a gradual and constant elevation of the land: now, without supposing this to have continued during the period of the formation of these rocks, what an immense depth the Mediterranean must have had at the time the lowest deposit was accumulating; and the same would be greatly increased, if the calculation was founded on the more extensive deposits of Italy. The testacea and corals found in these rocks are said to resemble, for the most part, the inhabitants of the adjacent sea: have they not then more the character of littoral than of pelasgic creatures? And if so, is it not probable that these tertiary rocks, during their deposition, experienced successive subsidences, in order to preserve the sea nearly at its present depth.

But we must return from these speculations to a narrative of facts. It has been stated, that the tertiary deposits of Sicily are elevated many thousand feet above the present sea-level; and, in whatever manner this has been effected, a great part, if not the whole of them, have not undergone any considerable derangement by this change of position. And so it is with numerous marine deposits in various parts of Europe, which occur at great heights above the sea, and yet are arranged in horizontal strata. Now, if these deposits have been raised into their present elevated position by the expansive power of the central fire, it must be admitted that the inclined rocks, on which they rest, have also been exalted to the same extent; that is, that all Europe has been moved by this internal power, without any general disturbance in the previous arrangement of its rocks.

Such is the general condition of rocks which now appear far above the level of that ocean in which they were once submerged. And, before we determine on the nature of that elevation, let us enquire what alteration in the position of the strata has been produced by the intrusion of trap rocks.

"On the summit of the limestone platform of the Val di Noto, I more than once saw," says Lyell, "dikes not only of lava, but of volcanic tuff, rising vertically through the horizontal strata, and having no connection with any igneous masses now apparent on the surface." *

Dr. Macculloch, in his account of the trap rocks of Skye, has pointed out the structure of the different kinds, and the nature of their connection with each other. His observations on the trap-veins which traverse the stratified rocks of Strathaird are particularly important. These veins generally consist of a bluish black basalt, which is sometimes porphyritic, and assumes the ordinary appearances of this rock. One of

* Principles of Geology, vol. iii. p. 70.

these veins contains a second vein, holding a serpentine course through the first in a somewhat parallel direction, and readily distinguished by being formed of a much more black, durable, and compact basalt. These veins are often stratified, or, more properly speaking, laminated in the direction of their length. Their direction is almost invariably either vertical or slightly inclined from the plumb; and they present, therefore, a perpetual parallelism along the coast. They are equal throughout, and never ramify; and although they vary from five feet to twenty in breadth, they seldom exceed ten feet. Although these veins are so large and numerous, not the slightest disturbance takes place in the evenness and the horizontality of the strata of sandstone which they intersect: there is neither contortion, bending, fracture, nor displacement; nor do they appear to have affected the texture of the rock, since it is the same both at the place of contact, and at a distance therefrom. Nor must it be omitted to remark, that these trap-veins, in some places, nearly equal in extent the stratified rock through which they pass. If the lateral dimensions of these veins collectively be assumed to equal one-tenth part of the stratified rock (and this estimate does not appear to be excessive), the latter rock must have undergone a lateral extension equal to that quantity; a motion so great, that it is extremely difficult to reconcile it with the present apparent repose and regularity of the whole.*

The occurrence of trap-rocks, among the carboniferous and older greywacké groups, has been recorded by many observers: sometimes they intersect these strata without producing any alteration in their position, but very commonly they produce displacements, the strata, on one side, being at a different level to those on the other; and when many trap-dykes occur, then there is a great complication of these appearances, as also when only seams of dislocation are present, as in the case of the Jarrow Colliery, near Newcastle.

* Geol. Trans., vol. iii. p. 79. *et seq.*

De la Beche, in his description of southern Pembrokeshire*, states, "that the trap of this district, which is generally associated with and subjacent to greywacké, such as would formerly be termed transition-trap, supports contorted beds of old red sandstone, at Millhaven, and is incumbent on carboniferous limestone and coal-measures at Goultrop Head." "It would be difficult," he adds, "to explain these phenomena by any other hypothesis than that of the forcible intrusion of trap among the other rocks, at a period subsequent to that of their being formed and consolidated." The question, however, for our more immediate consideration, is the dip of these strata near the trap, which this excellent observer informs us is generally very elevated, and sometimes perpendicular. The bearings or strikes of these ranges of trap appear to correspond with those of the strata: thus, in the southern part of the district, the bearings of both are nearly E. and W., the strata dipping for the most part towards the south: in the northern part the trap of Pencarnon is about N. and S., and the strata, on the western side, dip to the W., "varying N. and S., conformably to the trap range which stretches from Crosswoodig." As regards the amount of dip, between the trap ridges of Cesselvawr and Llacithty, the beds of greywacké are perpendicular; immediately south of the latter they are also perpendicular; thence to Cuffern range they dip towards the south, as they do also on the southern side of the same range; they are nearly vertical at Guildford, north of the trap range of Bolton, whilst they dip on the opposite side of the range, towards the south, at various angles, varying from 20° to 50°; the strata of greywacké, on the south side of the wedge-shaped mass of trap, at Marloes, dip S., and of the red sandstone, on the northern side of the same, have a like inclination, both rocks dipping at considerable angles; and, as the breadth of the trap diminishes, these rocks gradually approach each other. If, then, the

* Geol. Trans. (New Series), vol. ii. p. 1.

position of these strata, next the ranges of trap, be attributable to the protrusion of the latter, whence this want of uniformity in the results? sometimes the strata are perpendicular on both sides, sometimes only on one; or, they are inclined on both sides in the same or different directions: nor must it be omitted to be remarked, that, owing to the curvatures of the strata, the same discordant dips may be seen where no trap is present; as also holds good with respect to contortions, which sometimes occur, and at other times not in the vicinity of trap; moreover, this protruded trap itself is sometimes composed of strata equally elevated, for "the southern part of Skomer Island consists of stratified greenstone, dipping at about 48° to the S. E." Here the supposed cause and effect are so confounded, that, even admitting the trap of Pembrokeshire to be an igneous intrusive rock, it does not follow that it has caused the elevation of the adjacent strata.

But we must not omit to notice an instance of elevation of a less doubtful character, which has been recorded by Lyell in his description of the largest of the Cyclopian islets. "The summit and northern sides," he says, "are formed of a mass of stratified marl (creta), the laminæ of which are occasionally subdivided by thin arenaceous layers. These strata rest on a mass of columnar lava, which appears to have forced itself into, and to have heaved up, the stratified mass. This theory of the intrusion of basalt is confirmed by the fact that, in some places, the clay has been greatly altered and hardened by the action of heat, and occasionally contorted in the most extraordinary manner, the laminæ not having been obliterated, but, on the contrary, rendered much more conspicuous, by the indurating process." *

Now, this case appears to be a most conclusive example of the elevation of strata by igneous rocks, inasmuch as the beds are not only inclined, but are also said to be altered by the protrusion of the lava in a state of incandescence. Even

* Principles of Geology, vol. iii. p. 79.

admitting this example to be correctly described, it cannot prove that all igneous rocks, including granite, have operated in the same manner, in opposition to the numerous instances which have been adduced, to show the possibility of the inclined position of the strata having had another mode of origin. But we think it not improbable that the supposed metamorphic schist is only a foliated variety of the lava; for we know that this configuration occurs both in the masses and veins of basalt, greenstone, syenite, porphyry, and other intrusive igneous rocks. "It is occasionally combined with the columnar form," says Macculloch, "and takes place either transversely or parallel to the axis of the prism. If often obscure and limited to small portions of an amorphous mass, it sometimes occupies a considerable space, and is so distinct, that the dark blue claystones, thus constituted, might be almost mistaken for clay-slate; though, as formerly remarked, it is seldom perceptible but on surfaces under the influence of the weather." * "The foliated structure of the lava-rocks," says Poulett Scrope, "is often accompanied by the columnar, of which it is wholly independent." "A remarkable example of this united structure occurs in the Roche Tuilière, in the Mont Dor. The clinkstone of which this rock is composed (an insulated fragment of the vast current descending from the Puy Gros) is regularly divided into nearly vertical columns. It is so extremely schistose (as the vulgar name of the rock implies), that its laminæ are used as slates for roofing." † If our conjecture has any foundation, then we can readily account for the position of the strata, by the existence of the highly inclined igneous rock before their deposition.

Now, the first part of these details, concerning the trap-rocks, accords well with the phenomena of existing volcanos; and it may therefore be concluded that the analogy between these igneous rocks is so far complete: but the second part of

* System of Geology, vol. ii. p. 138. † On Volcanoes, p. 143.

these details does not so satisfactorily point to the same conclusion; though it affords indications that the trap-rocks are sometimes accompanied by highly inclined strata, after the manner of the primary unstratified masses. If, however, we extend the comparison between trap and granite, it will be found that, although some points of resemblance exist, there are some of a very different character; and none more so than the mode of the arrangement of the strata adjacent to these rocks, the subject now under consideration.

The strata which surround granite are generally highly inclined, often dipping for many miles in a uniform direction, and sloping on either side from the central rock, which thus forms a ridge or anticlinal axis. They are supposed to have been elevated from a horizontal position by the protrusion of granite in a fluid or solid state, effected by the expansive agency of the central fire.

It has not, however, been satisfactorily demonstrated that the central fire can operate in this manner; but it has been shown that it is capable of elevating whole continents, in which case the strata generally suffer no disturbance, hills and valleys retaining their previous relations: and surely a power adequate to produce such vast effects, might have been expected to elevate the strata into inclined positions, if such were the usual mode of its operation.

For the sake of argument, let it be admitted that the granite, in a fluid state, has tilted up the strata: and that the latter were in a state of semi-fusion, or not, according as the supposed contortions of these rocks require a degree of ductility. Could horizontal strata be elevated to considerable angles, and even into a perpendicular position, without sustaining cracks and fissures? If not, how came it to pass that these attenuated, if not fissured, strata could, contrary to all known laws, oppose a force capable of protruding a mass of granite many leagues in diameter? In the cases of mines in warfare, of blasting of rocks, or of the bursting of steam-boilers, if a breach of continuity be once effected, an explosion immediately follows: so we should expect the same to take place if the incumbent strata were broken through by granite under the circumstances just specified; and, the fluid granite having found a vent, the strata, freed from the pressure, would fall back into their original position.

In the contemplation of the effects of a force much inferior to that just considered, viz. the production of elevation-craters, as propounded by Von Buch, Lyell argues against the probability of such an elevation, and concludes with the following observation:—"Is it possible to conceive that elastic fluids could break through a mere point, as it were, of the earth's crust, and that, too, where the beds were not composed of soft yielding clay, or incoherent sand, but of solid basalt, thousands of feet thick, and that they would inflate them, as it were, in the manner of a bladder? Would not the rocks, on the contrary, be fractured, fissured, thrown into a vertical position; and, ere they attained the height of seven thousand feet, would they not be reduced to a mere confused and chaotic heap?" * How much more, then, ought we to expect that the protrusion of immense masses, many leagues in diameter, amongst the strata, so as to raise them to a considerable angle over immense tracts of country, could not be effected without producing cracks and fissures: and if this happened, that is, if the internal elastic force overcame the incumbent resistance, how could these strata escape total destruction?

Some attempt to get over this difficulty by supposing that the granite was sometimes protruded in a solid state; but the almost universal occurrence of granite-veins penetrating the slate, appears to be in favour of the opinion which considers the granite to have been in a state of fusion during such catastrophes.

It has been before stated that Sedgwick and Murchison have been induced to conclude that the granite of Arran,

* Principles of Geology, vol. i. p. 389.

and of the northern part of Scotland, has been elevated in a solid state. The disposition of the sedimentary rocks of Caithness has been already quoted as an argument against the elevation of the strata; and, it may also be remarked, that the gradual rising of the strata of the coal-field from Inverbrora to Clyne Kirk, from a moderate inclination of 20° to a considerable angle, within the narrow space between the latter place and the sea, is not of such a nature as might be expected to result from the elevation of the enormous mass of primary rocks with which the adjacent granite is continuous. Nor does the gradual developement of these strata, as they recede from the granite*, accord with their supposed formation in regular horizontal layers of equal thickness; although it is in conformity with the known mode of arrangement during the deposition of sediments on inclined surfaces.

The appearance of the brecciated rock at Sandside Bay is, however, thought to justify the conclusion, that the Ord of Caithness, a granitic rock, has been upheaved in a solid form through the oolitic deposits. "On the western side of this mass of granite the stratified rocks are in the utmost confusion, the limestone being not only highly inclined, but also crystalline and cellular. Close to the point of contact the same beds assume a brecciated structure, and even contain many fragments of the granite itself. The contiguous portions of the cliff are chiefly composed of this breccia, through which the red granite protrudes with much irregularity. Some masses of the conglomerate rest upon the tilted edges of the limestone, whilst others are of a wedge-shape, and appear as if they had been mechanically driven in among the shattered edges of the higher beds of limestone and sandstone. The cement of the conglomerate is generally granitic; it is, however, in some parts calcareous, and in other places it approaches to the character of sandstone: — one great block of sandstone, with the usual undulating surface, seemed to be

* Geol. Trans. (New Series), vol. ii. p. 355.

entangled in the granite. At the eastern extremity of this disturbed portion of the cliff there is no conglomerate, and the stratified beds cannot be traced into immediate contact with the intruding granite; neither do their dip and direction appear to have been much disturbed."* — "These disturbed brecciated masses seem to have been formed by the mechanical action of the granite, which must, in that case, have protruded in this place after the deposition of the beds of limestone."

This explanation, however, does not appear to us to be satisfactory; for it is not easy to conceive that, on one side of so small a mass of granite, the strata should be undisturbed, and, on the other, be severed into fragments, the protruding rock itself being at the same time fractured and dislocated. Might not the occurrence of this breccia be accounted for by reference to causes now in action? When the sea was at a higher level (and it is an important coincidence that fifty or sixty feet is about the average height of the ancient beaches above the present tides), the oolitic strata would, as now, be broken into fragments by the waves; and, being at the foot of a granite cliff, would, by the degradation of this rock, be mixed with its detached blocks; and the mass of this detritus would be arranged in the hollows and irregularities, resulting from the erosion of the elements; so that an alteration of the sea level, and a subsequent consolidation of the compound debris, would produce a rock resembling the breccia in question.

Again, these distinguished geologists have referred to the granitic conglomerate of Ousedale rivulet, as another proof of the violent elevation of the granite. "What was the exact state of the granite at the time the formation of the old conglomerate commenced, it is not perhaps necessary to enquire; but it is evident that mechanical agents, by some

* Geol. Trans. (New Series), vol. iii. p. 132.

means or other, produced a separation (almost without any fracture) of the crystalline constituents of the rock." *

But it is a curious circumstance, that, whilst the oolite is supposed, at Sandside Bay, to have furnished part of the materials of the breccia, the old red conglomerate of Bad-na-Bae had no share in furnishing its quota; but that the fragments are here entirely derived from the granite, not merely its surface having been broken up, but the solid rock, to the extent of about half a mile in thickness. This explanation may be calculated to meet the difficulties of the case, but can it be supported by any known analogy?

It may also be remarked, that the old conglomerate is generally arranged in highly inclined strata, either in contact with granite, or with the intervention of the granitic conglomerate: the angle of the dip, however, is very various, and sometimes approaches the horizontal: "in Kerwick Bay, for example, the old red conglomerate is distinctly stratified, and dips north at an angle, which is inconsiderable when compared with the high inclination of the primary rocks on which they rest." †

So also the old conglomerate of the mountains of Applecross occurs in regular strata, which are inclined at a moderate angle.‡ And the same fact has been observed in many places in the north of Scotland. These strata are not only slightly elevated in some cases, compared with the primary schistose rocks, but also rest on the latter in an unconformable position. "Thus, in a deep gully two or three miles from Cape Wrath, the laminæ of the gneiss are nearly vertical, while the beds of conglomerate are not inclined at a greater angle than 25°." § Also, "the hill of Craig-na-Vrechan is composed of old conglomerate dipping off the coast, at a low angle, and resting unconformably upon the micaceous slate-rocks of this district." ||

* Geol. Trans. (New Series), vol. iii. p. 140. † Ibid. p. 127.
‡ Ibid. p. 155. § Ibid. p. 154. || Ibid. p. 127.

It is particularly worthy of remark, that these conglomerates not only vary in the amount of their dip in different places, but "consist essentially of fragments, more or less rounded, of the nearest primary rocks, but never contain any substance resembling the Caithness schist or sandstone." * It may therefore be presumed that the primary strata were elevated previous to the formation of the conglomerates, since the latter consist of the debris of the former, in consequence of their having been exposed to causes similar to those now in operation; and if so, then the surface of the primary rocks must have been reduced to a state of inequality, like that which now occurs in analogous districts. For example, we find the existing surface in primary districts variously inclined, but not corresponding with the dip of their strata; and, in those places where recent deposits occur, these may be arranged parallel to such superficial planes, or they may exhibit inclined concretional layers, superinduced by cohesion, and not coincident with the planes of deposition, as has been already discussed.

If, on the other hand, we consider the granite of this part of Scotland to have produced the different degrees of elevation exhibited in the adjacent rock, the following suppositions appear to follow from the facts now detailed. The granite, in the first place, must have been in a state of igneous fusion, not only to convert the sedimentary strata into crystalline or primary slates, but to produce the granite-veins, as at Loch Brora and at Cape Wrath; and then, or subsequently, when consolidated, it elevated these strata. Since that time, the granite must have been elevated at different periods, and under different circumstances, to account for the various appearances; for sometimes the secondary strata are highly inclined, with a gradual diminution of the angle as they recede from the granite; and, at other times, they are less elevated, and unconformably arranged in the older strata: in

* Geol. Trans. (New Series), vol. iii. p. 138.

some cases, we find no marks of destruction in the strata through which the granite has protruded, and in others they are detected, but in one instance only, on one side of the granite and not on the other; and, again, the strata have escaped, whilst the granite itself, to a great extent, has been shattered into innumerable fragments: and it must further be observed, that this upheaving power must have caused an elongation and attenuation of the strata in its progress upwards, in order to account for the wedge-shaped forms of these secondary deposits.

It did not escape the notice of the geologists on whose valuable details we are now commenting, that the phenomena of this part of Scotland require the supposition of successive elevations. "This description plainly shows," they observe, "that the granite of the Ord must have existed prior to the formation of the old conglomerates: this fact does not, however, prove that it then existed at its present elevation; nor, according to our view of the subject, does it in any way invalidate the hypothesis, which considers the brecciated structure of the oolite to have originated in the last elevation of the primary crystalline masses of the Ord." * If we have not misunderstood these views, the numerous and complicated movements supposed to have happened in this comparatively small district of Scotland are referred to the repeated protrusion of granite through the stratified rocks, in a solid form. It is, however, very difficult to conceive the repeated action of such a stupendous power, as is in this case indicated, and in so narrow a compass, without producing utter confusion in the arrangement of the strata; besides, this explanation requires a mode of operation, the protrusion of one solid rock through another, which is, if we mistake not, without any parallel in the action of existing causes. We must confess that it appears to us, that all these phenomena may be more plausibly explained, by referring them

* Geol. Trans. (New Series), vol. iii. p. 140.

to the influence of known agents: the materials of each of these secondary rocks are such as atmospheric and aqueous causes would produce by their operation on older rocks; the position of these strata depends perhaps on the superficial form of the primary rocks on which they repose, and the amount of their angle of inclination may also depend on the same cause, or on the form of the concretionary layers of which these rocks are composed; and, lastly, the alteration which they have experienced at various times, as regards their situation above or below the sea level, may be attributed to the expansive power of the central fire, which, even at the present day, produces elevations and depressions of the land over extensive districts, without affecting the previous position of the rocks.

This view of the subject is at variance with the fundamental data on which M. de Beaumont's theory of the relative antiquity of mountain chains is founded: for, if inclined and horizontal strata may be continuous; and, if the degree of inclination may have arisen, either from the manner of deposition, or of consolidation, being in some measure regulated by the surface of the inferior rock on which it rests, but independent of the direction and dip of its strata; how is the period of elevation to be determined? Boué, Conybeare, Lyell, and others, have, on various grounds, advanced objections to this theory; and it may, therefore, be presumed that, without being modified, it cannot be maintained. It is not intended, at present, to enter on this topic, but to confine our remarks to the question whether horizontal strata, reposing on others which are inclined, furnish sufficient evidence that the latter have been upheaved before the deposition of the former.

"To determine the general unconformable position of two rocks, sometimes requires very great care," says De la Beche*;

* Geological Manual, 8vo. p. 481.

"though, at first sight, it may appear extremely easy to observe, whether one rock rests on the upturned edges of another, or not; and so it undoubtedly is, in many cases; but when they meet at small angles, or the one rests on the contortions of the other, the enquiry becomes more difficult, and it requires numerous observations to be certain of the general fact. When the contortions are small, the evidence is distinct; but when on the large scale, the great bends being measured by miles, instead of fathoms, the subject is not so easy. It may be stated, as an example, that the mass of the calcareous Alps is considered to rest unconformably on the mass of those composed of protogine, gneiss, &c.; but the situations where the contrary opinion may be formed are very numerous, the sections there exposing perfect conformability. It also requires great care in tracing strata up to a mountain range, for the purpose of ascertaining its relative antiquity, to distinguish between those beds which have been decidedly upturned subsequently to deposition, and those which may have originally taken a small angle during their formation, on the flanks of a chain previously elevated to a certain extent." Again, the same author has observed, that "a general unconformability does not always prove a movement in the inferior rocks, prior to the deposition of the superior: for supposing a given series to be so produced, that the newer rocks may be formed within successively diminishing areas, and another deposit to cover the whole; it is evident that the upper mass will so far rest unconformably on the inferior rocks, that it will cover them all in succession. Now, this is what has happened with the chalk and oolite groups in England. The angles at which the cretaceous and other rocks meet, in Dorset and Devon, are so small, that their unconformability could scarcely be determined at any particular point, though in the mass it is evident."

Thus we learn that, without entering on the more intricate problem of the nature of these inclined and horizontal strata, it is not even an easy matter, at all times, to determine the fact, whether strata are or are not conformable.

Sometimes groups of strata are found in mountain ranges, so differently inclined, that it has been deemed necessary to call in the aid of successive elevations, instead of one single convulsion, in order to account for these occurrences: indeed, they exhibit on the large scale the same intermixture of inclined and horizontal, straight and curved strata, as the laminæ of individual strata do, on a small scale, as detailed in the preceding chapter; and which it was attempted to show may depend on the angle at which the beds have been deposited, or on the structure which they have assumed during consolidation. Now the known irregularity of the present surface of the earth on which sedimentary rocks are forming, and the variously inclined seams which occur in shapeless masses of gravel and sand, would, *a priori*, lead us to expect, that the strata in any given district would exhibit different bearings and different degrees of inclination; and if these various dips be evidence of the elevation of the strata, how numerous and complicated these actions must have been. And thus it is, that most of the advocates of this doctrine have found it necessary, whenever they extend their observations, to call in the aid of many convulsions, where the author of the theory only laid down one anticlinal axis: Dr. Hibbert, for instance, in his researches on the Basin of Neuwied, ascertained that one derangement, corresponding with the valley of the Rhine, would not explain all the phenomena, as these require at least six or seven catastrophes for their satisfactory elucidation. But we need not dwell on a topic which has already been so ably handled by Boué, who has satisfactorily shown that De Beaumont has founded his speculations on too narrow a basis in this respect, since all subsequent details concerning the bearings of mountain ranges, have proved that the inclinations are much more complicated than was originally supposed. It remains, therefore, for farther investigations to ascertain, if possible, whether many of the appearances, which are now attributed to forcible elevations by the protrusion of igneous rocks, may not be explained by the operation of the less energetic, but not inefficient causes which have been indicated.

If, then, in the examination of the secondary rocks, so many difficulties present themselves, in determining the nature and origin of their inclined strata, it is not surprising that the more complicated structure of the primary slates renders this enquiry still more perplexing. Some may be of opinion that, in the latter case, the evidence of elevation is much more decisive, since the crystalline stratified rocks almost universally dip at great angles, and abound in curves, contortions, and other supposed marks of violent catastrophes.

On reference to the former chapter, it will be seen to what extent the primary slates are admitted to be analogous to the secondary rocks, it having been attempted to show that both are traversed by seams or joints, which arise from their concretional structure; and it is now proposed to offer arguments in support of the opinion, that the layers interposed betwen these parallel seams are in their original position.

It is, however, generally asserted, that the primary strata have been tilted up to their present highly inclined positions. But let us enquire, what are primary strata? This may be deemed superfluous, since they are such well-known objects, described by most geological writers, who have found no difficulty in recording their directions, dip, and other bearings. We must, however, confess that, after much personal examination, and the attentive perusal of the labours of others on this subject, we cannot answer this question.

Professor Sedgwick and some other geologists have regarded the primary strata of Cornwall to be parallel with the laminæ of these rocks. In conformity with the usual practice of giving the dip of the schistose rocks, we also followed the same course, and selected the bearings of the laminæ, because it is a point easily determined, whenever a small portion of rock is exposed; and because there is an advantage in having a certain criterion to guide us in forming our judgment. But it does not follow that this selection is correct. It is true that the position of the laminæ frequently corresponds with that which horizontal beds might assume, if tilted up; but this is not always the case, for the laminæ sometimes dip towards the granite, as well as in the opposite direction. Again, it has been shown that these rocks are intersected by other parallel planes, which cross the laminæ at various angles, but have the same bearing or strike; so that, as the planes of the laminæ most frequently dip from the granite, those of the other series incline most commonly towards this rock. Now it has been already stated, that the fissile structure of the slates is perfectly independent of the so called strata, since they are arranged at various angles thereto, in rocks not only of the primary, but also of every other geological epoch. Since, therefore, this structure does not infallibly denote the supposed order of deposition, why determine on the planes parallel thereto, in preference to those which have an opposite dip? There is one reason why the latter might be preferred: viz., that these planes are for the most part parallel with those of the massive rocks (greenstones, porphyries, and the like) with which these slates are associated.

In Cornwall, the *lamellar* system of planes seldom attains great angles, but fluctuates between 20° and 40°; whereas the others vary from 45° to 70°, and even higher inclinations.

What has been the rule for determining the selection in other countries? It does not appear that any fixed plan has been followed: sometimes, however, it has been cursorily remarked, that the laminæ cross the planes of stratification. On referring to Weaver's description of Ireland, in the fifth chapter, it will be seen that the mica-schist and clay-slate, next the granite, are stated, in some places, to dip at moderate, and in others, at considerable angles, — sometimes from the granite, and at others towards this rock; so that, if continued, they would either abut against, or underlie the granite. The same statements have been made by Macculloch, and other writers. Now, considering the hitherto undefined nature of the term stratum, we would enquire whether it is probable, that geologists have always selected the same denomination of planes? and whether they may not have regarded as the strata, sometimes one series of planes, and sometimes another; of which there are three series; one perpendicular, and two others variously inclined, as described in the chapter on the structure of the primary slates. May not this have happened, in some cases, from one set of planes being occasionally more distinctly developed than the other? or from the degradation, in cliffs and similar places, not having been always confined to the same direction, having been more extensive in one than another, and *vice versâ?* Lastly, we would ask, if these strata have been upheaved by the granite, how comes it to pass, that whichever series of planes be adopted as true strata, that, in Cornwall, the lines or seams which mark these planes are continued into the granite itself, dividing this rock into corresponding layers? This fact is not obscurely indicated on a single spot, but is displayed, in many places, in clear and bold characters, which cannot be mistaken; and which certainly cannot be reconciled with the idea of the forcible elevation of the strata, and of the protrusion of the granite.

On the grounds detailed in this chapter, we therefore conclude that the inclined position of strata is not an infallible criterion of mechanical elevation; that this appearance in the primary slates may be more justly attributed to their original structure, and in many of the secondary strata to the same cause conjointly with their deposition on inclined surfaces; and, that the notion of granite having been protruded through and tilting up the strata, either in a fluid or solid state, does not appear to be countenanced by reference to the known effects of igneous agency; and, lastly, that the situation of strata adjacent to trap-rocks, the supposed connecting link between the granitic rocks and existing volcanic products, is of too intricate and conflicting a nature to be received as positive evidence of such an occurrence.

CHAPTER XIV.

ARE THE PRIMARY SCHISTOSE ROCKS SEDIMENTARY DEPOSITS ALTERED BY THE CONTACT OF IGNEOUS ROCKS?

Passage of primary slates into secondary rocks. — Transitions of two kinds — mineral and mechanical. — The latter no criterion of identity. — The relative position of strata not easily determined. — The lias group of the Bötzberg. — The capability of caloric to alter rocks. — Lyell's remarks on this subject. — Sir James Hall's experiments on the fusion of rocks. — The state of rocks next actual lavas — also next trap — in Skye — in Anglesea — in Ireland. — Dolomization. — Strata next igneous rocks only partially altered. — These changes similar to the effects of caloric — condition of primary strata next granite — indicates a transmutation of one earth into another. — The contact of ignited granite and sedimentary deposits disputed. — The arrangement of primary slates incompatible with their being altered deposits. — These slates contain elements not found in sedimentary rocks. — The transfusion of alkalis analogous to that of magnesia in dolomite. — Objections to such transfusions. — The primary slates of Dartmoor — and the Hartz — said to be altered greywacké. — Those of the Alps altered oolitic strata. — The association of gneiss and limestone in Jungfrau — of granite and limestone in Glen Tilt and the Pyrenees. — Conclusion.

The metamorphosis of stratified deposits by the contact of igneous rocks in a state of fusion or incandescence, appears to be established by such a legitimate train of deductions, that it will probably be esteemed an act of great presumption to dispute its accuracy. And any objections advanced against this hypothesis, may naturally meet with a less candid consideration than the topics already discussed; because it is the offspring of the Plutonic theory, which has grown with its growth, and which certainly is so plausible, and so well adapted to give strength and support to its parent, and is withal so fascinating, that even its adversaries must attack it with no little reluctance.

In a former chapter it was attempted to prove, that the evidence by which the analogy between the primary and secondary strata is thought to be substantiated, is not free from objections. The same difficulties may be equally advanced on the present occasion; for, if the prevailing theory fails to show that the primary slates were once in the condition of sedimentary deposits — if it fails to demonstrate that the former, at the period of their formation, did perfectly resemble the latter — then it does not follow that the present nature of the crystalline slates has resulted from any superinduced action or metamorphosis; on the contrary, their existing state may be original. In the previous examination of this question, one important consideration which has been advanced in support of the crystalline slates being altered rocks, was omitted: before proceeding, therefore, to discuss the capability of caloric to effect such changes, the subject of this omission must engage our attention.

In tracing the nature and position of the stratified rocks which surround granite, from distant points up to the central unstratified mass, it has been remarked, that the fossiliferous strata appear to pass gradually into the primary slates which are in immediate contact with the granite. And, since these strata belong to various geological epochs, in different countries, it has been concluded, that the primary slates are altered rocks belonging to the same periods as the adjoining sedimentary deposits.

This is clearly and distinctly propounded; and is an argument not to be easily opposed, for it is based on the observations of the most experienced geologists; and it can, therefore, be only disputed by questioning the accuracy of their conclusions. This is a painful alternative, and more especially as we cannot appeal to Nature, and positively demonstrate the fallacy of the data from which they have formed their deductions; but can only advance our views of the subject, which may, very probably, prove equally fallacious. To differ from the best authorities on such grounds, may be deemed an unpardonable proceeding; but, as these distinguished philosophers are lovers of truth, we feel assured that they will candidly receive any suggestions which may lead either to the subversion, or to the firmer establishment of the theory which they advocate.

It is proposed, in the first place, to examine the nature of the transition or passage which occurs among the secondary rocks, and between these and the primary slates; and ascertain whether the evidence thus furnished is conclusive, that all rocks so connected have had the same origin, and belong to formations of the same epoch.

In the primary rocks, transitions appear to be effected in two ways: in the one, the crystalline constituents, when the rocks are compound, or the component particles, when simple, gradually pass from large and coarse concretions to particles so minute as not to be detected by the eye; and during this change, rocks of very various aspects are produced, which are farther varied by a difference in the proportion of their component parts: this transition is very similar to that which commonly obtains amongst the secondary rocks, owing to the intermixture of two deposits; either in consequence of the sediment following the laws of gravity during its accumulation, or to the gradual change of circumstances under which they have been produced. In the other case, however, the transition between different primary rocks is accomplished by a gradual change, not only in the proportions, but also in the mineralogical characters of the constituent parts. Thus, the felspar and quartz of granite pass into granular and compact felspars, that is, into eurite and felsparite; mica, by degrees, assumes the properties of talc, shorl of hornblende, hornblende of diallage, or of chlorite; in short, many other transformations well known to geologists, and which, of course, are accompanied by a corresponding difference in the nature of the rocks. The latter may be called a mineral; the former, a mechanical transition.

When crystalline rocks are found to pass into each other by mineral transitions, it may be presumed that they do belong to the same formation: but when the passage is effected by a mechanical transition, numerous facts clearly show that the same conclusion must not be drawn; thus, it is difficult to lay down the precise line between the tertiary and the secondary formations, or, indeed, between some of the individual beds of their respective groups; all of which have evidently been formed at distinct periods.

This being the case, is it at all surprising, that it is difficult to separate the primary slates from the fossiliferous strata by which they are immediately succeeded? In Cornwall, a remote portion of the calcareous series contains organic remains characteristic of the oldest beds of the greywacké, or transition group; and there is no point between the slates of the porphyritic series in contact with the granite, and these fossiliferous beds, which can be asserted to mark the boundary between these series: though, as we have stated in another place, the same facilities for examination cannot be obtained as are offered at the junction of the slate with granite. Now, what happens in Cornwall has been frequently observed in several parts of the Alps and other districts, with the exception of the secondary strata belonging to different groups: but surely this apparent transition is no positive evidence that all the rocks so connected are of the same epoch; we have said apparent transition, as we are not aware that this has been actually determined by one continuous section intersecting these rocks, and perfectly exposed to view throughout its whole length.

It has already been shown, that the conglomerates and greywacké of Nare Point, Helford Harbour, in Cornwall, pass by insensible degrees into the adjacent slates, from the detritus of which they have been formed: and it is therefore evident, that the parent slates and the derivative rocks cannot have had the same origin. And the same conclusion is applicable to some appearances of this kind in Caithness, referred to in the last chapter. The strata of the old red conglomerate have been, according to Sedgwick and Murchison, tilted up by the protrusion of solid granite; during which catastrophe the latter rock was so shattered as to form a considerable bed of granitic conglomerate, interposed between the red conglomerate and the intrusive mass: here, then, we have three rocks, not only produced in different ways, but at three distinct periods, and yet they all gradually pass into each other.

Thus, also, according to De la Beche, "the undoubtedly mechanical greywacké around Dartmoor gradually passes into rocks having the characters of mica-slate next the granite, as shown on a line drawn from the southern part of Dartmoor to the sea, at the Bolt Head or the Prawle, a line which can be examined for the greater part along the sea-cliffs."

It is very probable that the fragmentary rock has, in this case, been formed of debris not far removed from the crystalline slates; and it may, in many parts, appear to pass into the latter, because, when the parent rock is partially changed by an incipient decomposition, it cannot be easily distinguished from the finer varieties of greywacké. In the cliffs in Mount's Bay, in Cornwall, the felspathic rocks, for instance the greenstones, become of a different colour during decomposition, which of course dies away by imperceptible shades, as we descend to the perfect rock: now suppose the disintegrated part to be again consolidated, the transition would then be perfect, and yet the upper and lower strata would not be precisely the same. But this case may be put in a much stronger point of view: for this bed of argillaceous debris, containing fragments of quartz and the harder portions of the parent rock, is sometimes thirty feet or more in thickness, and, at the bottom of the cliff, reposes on a horizontal stratum of sea-sand; and this deposit tapers upwards towards the hill, till it terminates in a wedge-shaped mass, such as so commonly belongs to secondary strata: at its upper part it is connected with the loose part of the decomposing rock just described, which has clearly not been moved, for the quartz-veins continue their course therein without alteration, whilst they are cut off and disappear in the wedge-shaped mass, which circumstance, conjoined with the position on the sand, indicates that the upper bed of debris has been transported: the time may come when these deposits will be converted into stone, and then would future geologists find derivative rocks, associated with sandstone, containing organic remains of the modern epoch, and yet passing by the most perfect gradation into crystalline slates, which are in contact with granite, and abundantly intersected by granitic veins.

It will be again necessary to revert to this topic, when the well-known observations of Hugi, Studer, Beaumont, and others, on the alteration of the strata by granite in the Alps, come under consideration; and, after making allowance for the distorted and disproportionate appearance of their sections, the dissimilarity of these phenomena and those just detailed is not so great but that it may be possible hereafter, when we are more minutely acquainted with the facts, to offer a plausible explanation, without having recourse to the supposition that the crystalline slates were once sedimentary deposits.

By way of illustration, take the Bötzberg in the Swiss Alps, described by Hugi and Studer. It is stated that the strata dip towards the granite, and that the latter rock, in descending the mountain, is succeeded by gneiss, which, in its turn, gives place to mica-schist, followed by limestones and slates belonging to the lias group. De la Beche, from whom we quote, remarks that, "assuming the section to be correct, the superposition of the crystalline rocks, in this case, is evident*;" and he offers two explanations of this unusual position; one referring it to the strata being thrown over, the other to the granite overflowing the fossiliferous beds. Now it has been already shown, that it is no uncommon occurrence to find parallel seams or joints traversing the secondary rocks as well as the primary, and dipping toward the granite, but

* Geological Manual, 8vo. p. 456.

it does not follow that these correspond to the planes of deposition; so the liassic slates and limestones of the Bötzberg may successively present themselves at the surface, exhibiting layers which decline towards the granite, and yet the entire mass of each of these rocks may be wedge-shaped, basin-shaped, or of any other form, ranging even in the opposite direction. The term stratum, and all its properties of bearings and dip, both longitudinal and lateral, have been so variously and indefinitely used, that we cannot form any correct idea of the relative position of rocks, unless all the minute circumstances of the case have been carefully detailed. If, in addition to this difficulty, it be remembered that the earthy materials of the liassic slates have very probably been derived from the debris of the crystalline rocks, immediately or through the medium of a previous migration; and, since this debris uniformly contains scales of mica, more or less abundant, it is not surprising that a mechanical transition should here occur; but, at the same time, we cannot admit this as infallible evidence that the mica-slate and gneiss are identical with the strata of lias, only differing therefrom in consequence of having assumed a new aspect, superinduced by their contact with granite in a state of incandescence.

It is time, however, to discuss the capability of caloric to effect such metamorphoses, a topic which can be more satisfactorily approached, since the arguments advanced in its support depend more on facts than opinions. "The geologist," says Lyell, "has been conducted, step by step, to this theory, by direct experiments on the fusion of rocks in the laboratory, and by observation of the changes in the composition and texture of stratified masses, as they approach or come in contact with igneous veins or dikes. In studying the latter class of phenomena, we have the advantage of examining the condition of the rock at some distance from the dike, where it has escaped the influence of heat, and its state where it has been near to or in contact with the fused mass. The changes thus exhibited may be regarded as the results of a series of experiments, made on a great scale, by nature, under every variety of condition, both as relates to the mineral ingredients of the rocks, the intensity of heat or pressure, the celerity or slowness of the cooling process, and other circumstances." *

We need not enlarge our details by relating the well-known experiments of Sir James Hall on the fusion of rocks, by which we learn that a melted rock assumes various appearances on consolidation, according to the rate of cooling. We would, however, gladly enumerate the conditions of sedimentary rocks at their point of contact with currents and dikes of recent lava, that is, of undoubted volcanic rocks; but we do not remember that such have been recorded, for although the interference of lava of the modern epoch with strata has been described, yet such lava is ancient, and cannot furnish evidence so important as that which is now actually produced by existing volcanos.

The altered appearance of sedimentary deposits next trap is of very common occurrence, and we shall therefore quote a few examples, in order to show the precise nature of this phenomenon.

At Duntulm, in the north-western part of Skye, an obscurely columnar trap covers beds of shelly limestone and of sandstone, containing shells and carbonised wood, alternating with shale: the junction of the trap and strata is, in many places, attended with great confusion. The upper part of these strata, about twelve or fifteen feet in thickness, is divided into thin laminæ, which have the appearance of shale alternating with limestone: but when fragments are broken off and closely examined, the schist is found to be of a black colour, very hard and brittle, sharp in the fragments, and with an obscurely rhomboidal fracture; in short, it is a kind of siliceous schist, a Lydian-stone: the sandstone is found to possess

* Principles of Geology, vol. iii. p. 367.

great hardness and a jaspideous aspect, similar to that sandstone which is in contact with the greenstone of Stirling Castle.

"Considering, therefore, the analogy of these two sandstones, we may fairly conclude," says Dr. Macculloch, "that they have, in these instances, been altered from their original texture, in consequence of the proximity of the trap-rock: and we have an equal right to conclude that the same influence has also converted the shale into Lydian-stone. This, in fact, is the position of every specimen of this stone which I have seen in Scotland. In Conachan, in Raasa, in Shiant, at Talisker, it forms beds in contact with and involved in trap, which, from their connection and position, appear to have been common clay-slate."*

But one of the most important examples which has hitherto been adduced on this subject, is the modification of strata next a basalt dike, near Plas Newydd, in Anglesea, described by Professor Henslowe in the Cambridge Philosophical Transactions. "The dike (we quote from Lyell) is 134 feet wide, and cuts perpendicularly through strata of shale and argillaceous limestone, which are altered to the extent of thirty feet from the dike. The shale, as it approaches the basalt, becomes gradually more compact, and is most indurated nearest the junction, where it loses part of its schistose structure, but the separation into parallel layers is still discernible. In several places the shale is converted into hard porcelainous jasper: in the hardest parts of which the fossil shells, principally Productæ, are nearly obliterated; yet even here their impressions may be frequently traced. The argillaceous limestone undergoes analogous mutations, losing its earthy texture as it approaches the dike, and becoming granular and crystalline. But the most extraordinary phenomenon is the appearance in the shale of numerous crystals of analcime and garnet, which are distinctly confined to those portions of the rock affected by the dike."†

* Geol. Trans. vol. iii. p. 99.
† Principles of Geology, vol. iii. p. 368.

"The induration," says Dr. Berger, "which the secondary rocks undergo, when traversed by dykes of trap, has often been noticed; it is not my intention now to discuss this subject: I shall only mention that the induration does not extend far from the dyke, and that the phenomena, though very frequent, are not universal." * "In general, there is no foreign matter between the substance of the dyke and the rock it divides, except a slight rusty appearance on the surface of the latter. The contact between the two is pretty close, but they may always be disjointed by the blow of a hammer." †

Before proceeding to make any remarks on these observations, it will be well to relate the nature of the phenomena alluded to, as detailed in the same paper, on the north-east of Ireland, by the Rev. W. Conybeare. "At Redbay Castle, several basaltic dikes traverse the conglomerate: one of these, remarkable for its great thickness, having resisted the action of the waves, which have encroached considerably on the adjacent cliffs, presents some bold detached crags projecting from the beach. The conglomerate forming the wall of the dike has undergone a great degree of induration, its cement assuming the appearance of a compact hornstone; thus it has been enabled to oppose to the sea a resistance almost equal to the basalt itself, and is still seen adhering on the sides of the advanced crags." ‡

"The whin dike of Carrick Mawr forms a broad causeway, traversing the beach, and terminating in a nearly insulated mass of rocks rising about thirty feet; of this mass only the central line consists of the dike itself, the sides being evidently composed of portions of the strata traversed by it, but much altered in their character and degree of induration by its contact. These beds appear to have been chiefly derived from the slate-clay of the coal measures, which has become so compact as to assume the character of flinty slate. In one point, this rock may be seen on one side, and on the other,

* Geol. Trans., vol. iii. p. 230. † Idem, p. 231.
‡ Idem, p. 201.

the sandstone grit which usually accompanies the coal beds, also in a highly indurated state; its colour changed from red to white, and its mass penetrated by minute grains of iron pyrites. At fifteen yards distance from the dike, the alteration ceases, and the sandstone resumes its usual character, becoming reddish and destitute of pyrites. Where the dike traverses the great insulated mass of slate, it is very irregular both in thickness and direction. The works of the Gob colliery have reached this dike 500 yards inland from the face of the cliff: the coal is altered by it to a considerable distance from its point of contact, being reduced to the state of a cinder, which can be employed only for burning lime. This dike throws out the measures of Gob colliery, which are not recovered on its eastern side: its breadth is about twelve feet where it comes to the surface of the cliff, but varies considerably in different parts of its course." *

"The peninsula of Portrush, which may be about a mile in circumference, is fenced with low cliffs on the west, north, and east; those on the west present a rude prismatic greenstone; those on the north and east, tabular masses of greenstone, overlying, and in some places appearing to alternate with a very remarkable rock. It is a flinty slate, exactly similar to the indurated slate-clay which forms the wall of the Carrick Mawr dike, in the Ballycastle collieries; and the analogy is rendered the more striking from the further resemblance of the greenstone of that dike to the greenstone of these cliffs. In this flinty slate are contained numerous impressions of Cornua ammonis invested with pyrites, the shells being similar to those found in the slate-clay underlying the chalk near Ballintoy: and we felt convinced, while examining the spot, that the rock was no other than the slate-clay of the lias formation, in an indurated state." †

"The chalk is frequently traversed by basaltic dykes, and often undergoes a remarkable alteration near the point of

* Geol. Trans., vol. iii. p. 205. † Idem, p. 212.

contact; where this is the case, the change sometimes extends eight or ten feet from the wall of the dike, being at that point greatest, and thence gradually decreasing, till it becomes evanescent. The extreme effect presents a dark-brown crystalline limestone, the crystals running in flakes as large as those of coarse primitive limestone; the next state is saccharine, then fine-grained and arenaceous; a compact variety, having a porcelainous aspect, and a bluish grey colour, succeeds: this, towards the outer edge, becomes yellowish white, and insensibly graduates into the unaltered chalk. The flints in the altered chalk usually assume a grey yellowish colour; the altered chalk is highly phosphorescent when subjected to heat."*

We must not quit the subject of the metamorphosis of limestone by the contact of trap, without noticing the crystalline magnesian limestones which are supposed to have been originally common limestone converted into dolomite by porphyry and similar igneous rocks. Many objections might be urged against the possibility of the introduction of magnesia into this rock; but the difficulties of the case have been so fairly stated and discussed by De la Beche †, that we need not insist on the imperfect state of this hypothesis. There is, however, one point which may be alluded to, because it is directly opposed to the nature of the supposed altered chalk of Ireland; viz., the occurrence of organic remains in dolomite, which, in the other case, are said to have been obliterated by the fusion requisite to impart a crystalline texture to the earthy carbonate.

We have been thus particular in detailing these examples at some length, not only because the original works may not be within the reach of all our readers, but also because it is important to bring all the minutiæ of these cases into one point of view.

It is, therefore, by these, and numerous phenomena of the same nature, clearly established that the stratified rocks,

* Geol. Trans., vol. iii. p. 172. † Geol. Manual, 8vo., p. 474, et seq.

immediately in contact with trap, basalt, and analogous rocks, do not always present the same appearance as at a distance therefrom: and since the latter rocks, in all probability, are of igneous origin, it has been concluded that this difference has been caused by these rocks having been brought into contact with the strata in a state of ignition; whereby the sedimentary deposits have been variously affected, according to their composition. This view of the subject is further corroborated by the fact that these changes, with the exception of dolomite, are such as might be produced by heat.

There is, however, a most important consideration arising out of this investigation, which must not be overlooked. Admitting that these changes may have arisen by the presence of intensely heated trap rocks, how comes it to pass that a like cause has not always produced a corresponding effect? How is it, if these rocks have been intruded among the strata in a state of ignition, that they have not equally altered the same rock throughout their entire course? For it is not easy to conceive the reason why the basalt-dikes in Ireland should change the chalk only in insulated patches; or why dikes of the same nature sometimes reduce coal into coke or cinder, and at others traverse it without producing any alteration; or why the sandstones and shales are not always converted into hornstone, jasper, Lydian stone, and flinty slate, when intersected by igneous rocks. That this anomaly really does exist, might be proved by numerous details; but it is a fact so often noticed, that it may suffice to refer to the statement above quoted from Berger, that the phenomena of induration of strata by the contact of basalt, though very frequent, are not universal; and to the works of Macculloch, which, among many other examples, record that, in Skye, large dikes of basalt, running perpendicularly through the sandstone at Stratnaird, have not affected the texture of the rock; whilst at Duntulm, in the same island, the sandstone at the points of contact have assumed a jaspideous aspect.

The same anomaly also obtains in the case of the dolomite in contact with augite porphyry in the districts of the Lakes Orta, Maggiore, and Lugano, as described by Von Buch: dolomite is generally interposed between the limestone and porphyry, but, in several instances, the limestone joins the porphyry, without having experienced the metamorphosis attributed to the presence of this igneous rock.

The supporters of the Plutonic theory must often have observed similar facts, but we do not know whether they have made an attempt to explain how a heated mass, capable of effecting such changes, could have remained in contact with strata, without producing any alteration: if this subject has not yet attracted their attention, it is deserving of their serious consideration. In conducting this enquiry, it may be suggested that the position of the igneous rock should always be marked, and the precise parts, whether upper or under, where the strata have been changed; and the degree of alteration that has taken place, — in short, all particulars, — should be noted; for circumstances, which may often appear to the enquirer minute and trivial, may be hereafter regarded as very important, and tend to throw some light on this subject.

In the mean time, it is proposed to admit, for the sake of argument, that the alteration of the strata, above considered, has been produced by heat; and, after having stated the nature of this change, to enquire whether the metamorphoses which the primary slates are supposed to have undergone are analogous.

The strata next the trap rocks are sometimes indurated, assuming such an appearance as might be supposed would result from a long-continued and high temperature; and sometimes they appear to have been altered by a partial or total fusion: thus, sandstone assumes the character of hornstone, jasper, or even solid quartz: clay-slate and shales are converted into flinty slate and Lydian stone, and even garnets are then found which did not previously exist in the schistose rock; and secondary limestones become perfectly crystalline, their organic remains at the same time disappearing, so that they cannot be distinguished from some primary marbles. But, great as these changes undoubtedly are, they may all be attributable to the action of heat alone, except in the case of dolomite, where a new element is supposed to be introduced; a supposition, however, which must be established on more certain evidence before it be an acknowledged exception to this general rule.

Much light cannot at present be thrown on this subject by a reference to existing chemical analyses; but a table is subjoined, in the hope of directing attention to the importance of this evidence. That experiments of this nature have not hitherto been either numerous, or very accurate, is not surprising; for an indiscriminate analysis of these rocks offers little inducement to the chemist, because the compounds are very indefinite, on account of the constant variation in the proportions of the constituent parts. But if the geologist would carefully select important examples, minutely recording all the circumstances of position and association, then the assistance of the chemist would be a valuable acquisition. Such an union has, indeed, already commenced; and the example of Turner and De la Beche must be hailed as an important event in the history of our science.

Imperfect as the following table is, it teaches us that the volcanic or igneous rocks generally contain an alkali, whilst the derivative slates are devoid of this substance; indeed, we might conclude, *à priori*, that all rocks composed of earthy substances, derived from the decomposition of crystalline formations, would be so circumstanced, since the alkali is always extracted from such during chemical disintegration.

A TABLE

OF THE COMPOSITION OF SOME ROCKS WHICH OCCUR IN THE FOSSILIFEROUS GROUPS.

	Sil.	Alum.	Mag.	Lime.	Pot.	Soda.	Iron Oxide.	Mang.	Carb.
Basalt									
(Klaproth)	44·50	16·75	2·25	9·50	—	2·06	20	0·12	
(Kennedy)	48	16	—	9	—	4	16	—	
Compact felspar									
(Mackenzie)	71·17	13·60	—	0·40	3·19	—	1·40	0·10	
Porcelain jasper									
(Rose)	60·75	27·25	3	—	3·66	—	2·50	—	
Clinkstone									
(Klaproth)	57·25	25·50	—	2·75	—	8·10	3·25	0·25	
Pitchstone									
(Klaproth)	73	14·50	—	1·00	—	1·75	1·00	0·01	
(Knox)	72·80	11·50	—	1·20	—	2·85	3·03	—	
Pumice	77·05	17·05				3·00	1·75		
Flinty slate									
(Wiegleb)	75	the remainder being lime, magnesia, and oxide of iron.							
Lydian stone									
Clay slate									
(Kirwan)	38	26	8	4	—	—	14	—	—
Drawing slate									
(Wiegleb)	64·06	11	—	—	—	—	2·75	—	11
Adhesive slate									
(Bucholz)	58	5	6·50	1·50	—	—	9	—	—
(Klaproth)	82·50	0·75	8	0·25	—	—	4	—	0·75
Kaolin									
(Rose)	52	37	—	—	—	—	6·33	—	—

It will also be remarked, in this and a succeeding table, that porcelain jasper, and analcine, both of which are said to have been formed by the metamorphic action of basalt on sedimentary strata in Anglesea, contain an alkali. These substances, therefore, differ from all similar altered rocks, and must be added to dolomite in the list of exceptions. We might attempt to solve this difficulty, by suggesting that, as part of a bed of compact felspar often possesses a schistose structure, as does also even a mass of crystalline lava, so might this basalt, and the analcine might be confined to such slate at the junction of the igneous and aqueous rocks; or the jaspideous rock might have resulted from the combination of the fixed basalt with the shale at their point of contact.

It is time, however, to turn our attention to the primary rocks; in order to enquire whether the slates of this class owe their crystalline condition, and their exemption from organic remains, to the influence of granite, and other unstratified rocks, in a state of ignition. "According to these (Plutonic) views," says Lyell, "gneiss and mica-schist may be nothing more than micaceous and argillaceous sandstones, altered by heat; and, certainly, in the mode of their stratification and lamination, they correspond most exactly. Granular quartz may have been derived from siliceous sandstone, compact quartz from the same. Clay-slate may be altered shale; and shale appears to be clay that has been subject to great pressure."* Without, however, following this exposition farther, we will proceed to show that the changes which the sedimentary strata exhibit, next trap, are not perfectly similar to the condition of the primary slates; thus furnishing an additional argument against the analogy which is supposed to exist between the primary and fossiliferous strata.

It has been attempted to show, in a former chapter, that the lamination or structure of these rocks, though often similar, does not depend on stratification, or rather on the mode in which they have been deposited; and in the beginning of this chapter, it has been advanced, that the transition between the primary slates and the adjacent secondary strata does not infallibly prove that they belong to one and the same epoch. Still, however, even considering these topics to be disposed of, the question whether the primary strata are altered rocks, involves some other important considerations: and none of greater moment, than whether granite has actually been in a state of igneous fusion since the formation of the primary slates; for the whole question necessarily depends on this point, which we think has not been satisfactorily established, but which for the present may be conceded.

* Principles of Geology, vol. iii. p. 373.

If, then, granite has been brought into contact with the stratified rocks in a state of incandescence, what effect has it produced thereon? If its action has been analogous to that of trap, "it must have altered their texture; and this alteration must exhibit every intermediate gradation between that resulting from perfect fusion, and the slightest modification which heat can produce."

Now, what is the fact? The primary slates, at their junction with granite, have generally a different appearance from those parts of the rock that are more distant; and they, in such situations, very commonly possess a finer texture, and a greater degree of hardness: but here the analogy with the altered condition of the secondary strata next trap terminates; for a closer scrutiny will show, that the difference, in the case of the primary slates, is not such as heat alone could effect, it has not arisen from any modification of induration or fusion, but by a chemical change in the proportions, or the nature of their constituent parts: and this circumstance not only applies to the schistose rocks, but in very many cases is participated in by the granite. Refer to the seventh chapter, describing the nature of these rocks at their junction, where several examples are minutely detailed. Can it be supposed, however potent caloric may be to change clay-slate into flinty slate, and sandstone into jasper, that it can convert one earth into another, alumina into silica, as indicated by the quartzose nature of clay-slate and other schists, when in contact with granite; or lime into silica, as exemplified in the limestone of Glen Tilt, where, as it approaches the granite, "its crystalline texture disappears, and it gradually assumes the characters of hornstone, effervesces slowly with acids, and gives, on analysis, a large portion of siliceous matter."

This transmutation of one earth into another, may not present any serious difficulty to those who can give credence to the hypothesis concerning the dolomization of limestone: but it is to be hoped that geologists will not sanction an opinion so utterly at variance with the principles of chemical science; for, if we attempt to pursue a path of our own, rejecting the aid of the kindred sciences, vague and groundless speculations will speedily usurp the place of cautious and rigid inductions.

The metamorphosis, however, which is supposed to have been produced on the strata by granite, has not, according to this theory, been confined to the point of contact, but has extended to very considerable distances therefrom; converting sandstones into gneiss and mica-slate, shale into clay-slate, and the latter into hornblende, schist, and various other crystalline slates.

In order to conceive the possibility of such an occurrence, we are called upon to imagine voluminous masses of melted granite to have been for ages in an incandescent state, in contact with sedimentary deposits: by which the latter, to the whole extent of the primary slates, were intensely heated for a long period, but nowhere to the point of fusion, though this is said to have been nearly accomplished in the case of gneiss.

That a volume of melted lava does remain for a long time in contact with the stratified rocks in volcanic vents, cannot be denied; but the amount of change thereby produced does not seem to have been ascertained: indeed, in this case, it cannot be easily examined; but, in the dykes which communicate with immense superimposed beds of trap, we might expect to find some data on which to form an estimate of this power, more especially as such trap is supposed to have been ejected from beneath under considerable pressure; therefore intensely heated, and under circumstances favourable to the metamorphosis of the adjacent strata. But these are not always changed; on the contrary, these igneous and aqueous rocks often lie side by side, undisturbed and unaltered.

It appears to us to be a conclusion too hastily drawn, that the granite has been in a state of fusion subsequent to the supposed deposition of the primary strata: for it follows, that such aqueous sediments must have been formed on a basis of previously existing rocks; and, therefore, the melted granite must have been injected between the sediments and fundamental rock, or the latter must have been converted by fusion into granite. The latter idea appears to be entertained by Lyell, for he imagines that the repetition of another series of movements, similar to those that have taken place during the secondary periods, may upraise the hypogene rocks (granite and crystalline slates) formed, and now forming, during the tertiary and recent epochs; "by which time, we imagine, that nearly all the sedimentary strata now in sight would either have been destroyed by the action of water, or would have assumed the metamorphic structure, or would have been melted down into plutonic and volcanic rocks." * This is certainly a very ingenious and beautiful theory: it maintains a most perfect balance of power between the conflicting elements of fire and water, since the earth, the subject of these contentions, is always preserved nearly *in statu quo;* for whilst the water overruns and subjugates the upper regions, the fire, *pari passu*, takes possession of the nethermost aqueous conquests, and annexes them to its dominions.

Such a successive series of action and reaction is certainly in accordance with the usual routine of natural operations; but it is not sufficient that a theory be ingeniously devised to meet the exigencies of certain difficulties, but its principles must be deduced from facts. Before, therefore, this theory be accepted, it ought to be clearly demonstrated that the internal fire is gradually extending its influence farther from the centre of the earth, contrary to the common opinion that the crust of the earth is increasing by secular refrigeration; and, in the next place, it ought also to be proved, that the internal fire has converted sedimentary deposits into granite and crystalline slates: and if these points cannot be established, of what value is the conjecture, however ingenious?

Some may think it a great waste of time to enquire into

* Principles of Geology, vol. iii. p. 382.

the worth of every hypothesis which has been from time to time engrafted on the original Huttonian theory: but it seems to us, that such examinations, if conducted with candour and caution, may be of utility, by leading to more extended researches. In this case, such good results may be expected; for not only farther geological scrutiny will be suggested, but the astronomer, meteorologist, and chemist, must also be applied to for assistance.

If our planet were originally in a total state of igneous fusion, its present condition shows that it has been cooled to such a considerable extent, that the general temperature of its surface is not now influenced by this internal fire, but depends on another and remoter cause; and what has taken place during the countless ages required for the production of the aqueous deposits, may be presumed to be still in operation. We can form some idea of the successive changes which might arise during the secular refrigeration of a melted mass, and we may offer plausible explanations of these changes on the known principles by which matter is governed under similar circumstances: but on what analogies can we picture to our imaginations a central fire, not only maintaining its existence, by some unknown supplies, but even extending its dominion, so as to fuse the rocks on which the oldest strata were deposited, and to bring the latter into a state of intense ignition over a considerable portion of the globe, and within a comparatively insignificant distance from the surface; a distance far less than the total thickness of the secondary and tertiary rocks, many of which must have been formed since the supposed conversion of these strata into the existing primary rocks. We have said that many of the fossiliferous deposits are supposed to have been formed anterior to some of the primary slates, the latter proceeding from the metamorphic state of the former; but we might, perhaps, have asserted, on evidence not inferior to that on which this hypothesis is founded, that this metamorphosis, if it ever happened, must have preceded the formation of all the secondary and tertiary deposits. "The principal effect of these volcanic operations in the nether regions," says Lyell *, "during the tertiary periods, or since the existing species began to flourish, has been to heave up to the surface hypogine (primary) formations of an age anterior to the carboniferous." Now, if he admits that these primary rocks are older than the carboniferous series, our assertion holds good, and it follows that the central fire did, according to the views under consideration, extend to the surface, once more reducing the whole globe to a state of incandescence. But we presume that this is not his meaning: he only intends to assert that their original deposition as aqueous sediments, and not their altered or metamorphic state, preceded the carboniferous formation. It matters however little which view be adopted, for the latter must be ultimately reduced to the same terms as the former; for since it is a well-attested fact, that the oldest fossiliferous strata contain, and indeed sometimes are made up of portions of the primary strata, or the so-called metamorphic rocks, which are immediately adjacent; it seems to be a necessary consequence, that the primary slates could not have been in the nether regions of the earth when the oldest secondary strata were forming, and not upraised until the tertiary period; for under such circumstances, how could their fragments and debris enter into the composition of the latter deposits? On the contrary, if we estimate former changes by reference to causes now in action, this fact clearly indicates, that the primary slates must have existed before the oldest secondary rocks; that is, the parent must have been in being before the birth of its offspring: and not only so, but the former could not have been situated deep in the bowels of the earth when the latter were formed, but must have been previously in an elevated position at the surface, in order to have been subject to atmospheric and aqueous operations, which alone are capable of producing the detritus found in the composition of these secondary formations.

* Principles of Geology, vol. iii. p. 382.

This supposed metamorphosis of sedimentary rocks is, however, said to belong not only to strata older than the carboniferous, but actually to occur in strata belonging to some of the more recent secondary groups.

The nature of the transition between these groups and primary slates having been already considered, it remains to enquire whether caloric alone is capable of accounting for the difference between these two kinds of rocks. It has been shown, that the schistose rocks, at their junction with granite, not only differ from fossiliferous slates in their texture, as in the case of such slates next trap, but also in their composition; a chemical difference, which heat alone cannot be supposed to have effected. This is rather a serious difficulty *in limine*, for it cannot be attributed to the union of the granite and slate by fusion, since the lines of stratification, though obscured in gneiss, are allowed to be very distinct in limestone, hornblende, and argillaceous schists, and similar rocks; and it appears to us that this difficulty is not diminished when the scrutiny is extended to the whole mass of primary slates.

Presuming that the analogy of our furnaces, through the sides of which the effects of the fire do not extend beyond a certain point, though continued for several years; and of the glacier on Etna *, preserved from the action of a burning flood of lava by the sole intervention of a layer of volcanic sand, to be objectionable; and, admitting that the central fire can exert its influence through such an immense mass of non-conductors of caloric as the primary strata, we proceed to examine the changes which have been attributed to this igneous agent.

In the first place, the contact of melted granite (how called into existence is at present immaterial) has, according to the Plutonists, converted argillaceous sandstone, or some other sedimentary rock, into gneiss; which, adjacent to the granite,

* Lyell's Principles of Geology, vol. i. p. 371.

is very crystalline, not to be distinguished mineralogically from granite, and which, at a distance therefrom, though retaining the same component parts, is more perfectly stratified, and not so abounding in granite-veins.

How comes it to pass, it may be asked, since heat alone can produce gneiss from the sedimentary strata, that this primary schist is not always found in contact with granite? It may be answered, that the degree of intensity of the melted mass varied, and that other schists were produced when the temperature was not sufficient to form gneiss. This, however, would be mere conjecture; but it might be more plausibly urged, that the nature of the sedimentary rock induced a corresponding difference in the metamorphic rock: indeed, it has been stated, "that, as in the secondary formations, we find an indefinite series of clay, marl, sand, and limestone; so, in the primary, gneiss, mica-slate, hornblende-schist, quartz-rock, and marble, have no invariable order of superposition." This explanation, however, is more specious than correct; for all the primary slates, associated together in every possible combination, pass into each other so frequently by the most imperceptible gradations, and appear to be ultimately composed of the same elements, that it is difficult to suppose that they have been individually produced from such dissimilar substances as clay, marl, sand, and other deposits. To render this objection more obvious, we must refer to the primary slates generally. Clay-slate is said to be derived from shale, and when clay-slate comes into contact with granite, it passes oftentimes into hornblende-schist, which has been adduced as evidence of a more perfect igneous change, bearing the same relation to clay-slate, as granitic gneiss does to that which is distinctly stratified. Now, in Scotland, Norway, and those countries where granite and gneiss are characterised by containing hornblende, it is a common occurrence for gneiss and hornblende-schist to alternate together: so far the igneous theory goes hand in hand with nature; for if clay-slate be converted into hornblende-schist by the contact of fused granite, it might be expected that the same change would happen when interposed between two beds of gneiss; for the heat transmitted must have been very great, in order to form the more distant bed of gneiss. Is it, however, equally satisfactory, when the clay-slate is found alternating with gneiss, as in the islands of Iona and of Isla; or when, as in the same isles, and in various parts of Scotland, this slate gradually passes into and alternates with hornblende-schist? For if clay-slate, when heated to a certain degree, becomes hornblende-schist, by what laws of caloric could the intermediate beds of clay-slate have escaped this conversion? This argument is also applicable to gneiss: thus, in Tirey, and in other Scottish islands, the highly crystalline or granitic variety is found interlaminated with that which is regularly schistose; and not only so, but the latter sometimes completely envelopes the former, and this again encloses not only irregular veins and layers, but also entirely insulated nodules or masses of perfect granite. Turn again to the mica-slate and clay-slate of the eastern part of Ireland, as described by Weaver, and there too occur phenomena of the same import; and in Cornwall, the misnamed clay-slates not only envelope and are interlaminated with hornblende and other crystalline substances, but also contain insulated masses of granite, which, in one instance, at Herland Mines, have been discovered at a distance of two or three miles from the main granite. It is useless to multiply examples, for one is sufficient; the fact cannot be disputed, that rocks supposed to require an intense heat for their production, such as would fuse granite, are found enveloped in other rocks which could not have experienced such an elevated temperature. How are such capricious operations of caloric to be accounted for? The easiest method would be to doubt the perfection of a theory which has involved such a dilemma, or at least to reject the condition of the primary slates as evidence in favour of an igneous metamorphosis.

The objections already advanced appear to us to have no little weight, but our dissent from the prevailing theory does not solely rest on these grounds; for we are prepared to show that the slates, at their junction with granite, not only exhibit a difference of composition from that of the adjacent mass, but that the latter also contains an element which is not to be found in sedimentary clays, marls, and sands, from which they are supposed to have been derived. And, in order to establish this point, chemical analyses must be again referred to, and though these are certainly not so numerous or accurate as might be desired, yet they, perhaps, approximate near enough to the truth, to enable us to estimate the value of this argument. The compositions of several substances, which bear on this question, are given in the subjoined table.

From this table we learn that the proximate principles of all the compound crystalline slates, with the exception of quartz, contain no inconsiderable proportion of alkali, either of potash or of soda: but this substance does not form a component part of the secondary slates. This, indeed, is what might be expected *à priori;* for felspathic rocks, during their decomposition, lose their alkali, as in the formation of *porcelain clay* from granitic protogine and some kinds of eurite: indeed, the solution and abstraction of alkali from decomposing felspar appears to facilitate the rapid disintegration of the rocks which contain this mineral.

Those who support the conjecture concerning the dolomization of limestone will, of course, attribute the presence of alkali to a similar cause, to the transfusion of this substance through the primary slates; and in this case the opinion seems more tenable, magnesia being exceedingly refractory, whilst the alkalies may be fused and even dissipated in vapour, by an intense heat. Here, however, the same difficulty occurs as in the case of dolomite; the layer of rock immediately adjoining the granite does not always contain alkali, but is sometimes almost entirely quartzose.

A TABLE

OF THE COMPOSITION OF MINERALS CONTAINED IN THE PRIMARY ROCKS.

	Sil.	Alum.	Mag.	Lime.	Pot.	Sod.	Iron oxide.	Mang.
Felspar								
(Rose)	66·75	17·50	—	1·25	12	—	0·75	—
(Vauquelin)	62·83	17·02	—	3	13	—	1	—
Glassy felspar								
(Klaproth)	68	15	—	—	14·50	—	0·50	—
Analcime								
(Vauquelin)	58	18	—	2	—	10	—	—
Axinite								
(Klaproth)	50·50	16	—	17	0·25	—	9·50	—
Garnet								
(Wiegleb)	26·46	23·70	—	17·91	—	—	16·25	—
Compact felspar								
(Klaproth)	68	19	—	1	5·50	2·50	4	—
Saussurite								
(Ditto)	49	24	3·75	10·50	—	5·50	6·50	—
Mica								
(Ditto)	48	34·25	—	—	8·75	—	4·50	0·50
(Vauquelin)	50	35	—	1·33	—	—	7	—
Talc								
(Klaproth)	61·75	—	30·50	—	2·75	—	2·50	—
Shorl								
(Ditto)	36·75	34·50	0·25	—	6	—	21	trace
Chlorite						mur. of		
(Vauquelin)	26	18·50	8	—	—	2	43	
Hornblende								
(Klaproth)	42	12	2·25	11	trace	—	30	0·25
Diallage								
(Ditto)	60	—	27·50	—	—	—	10·50	—
Serpentine								
(Rose)	28	23	34·50	0·50	—	—	4·50	—
Asbestos								
(Chenevix)	59	3	25	9·05	—	—	2·25	—
Actynolite								
(Bergman)	64	2·70	20	9·30	—	—	4	—
Steatite								
(Klaproth)	45	9·25	24·75	—	0·75	—	1	
(Vauquelin)	64	—	22	—	—	—	3	

It may also be objected that some beds of primary rocks do not contain alkali, whilst others, with which they alternate, abound in felspar: that is, the same condition of these rocks which intimates that an emanation of caloric from a central igneous mass could not have produced the supposed metamorphosis, also renders it probable that the additional element, alkali, could not have proceeded from the same source. For, if clay-slate has been converted into hornblende and other crystalline schists, and the latter contain an alkali which is wanting in the clay-slate, and if the last-mentioned rock also alternates with mica-slate and even with gneiss, it is somewhat difficult to conceive how the alkali could have been transmitted through these interposed beds of clay-slate. The value of this argument rests on the composition of clay-slate, and we have made use of it on the generally received opinion of the nature of clay-slate: but we do not attach any importance to this example, because we do not subscribe to the general notion concerning this slate; indeed, the term clay-slate has been so commonly and vaguely applied to most schistose rocks of an uniform and fine texture, that it is, in fact, perfectly useless, as it conveys no definite meaning. On the contrary, we think that all true primary clay-slates, that is, such as are associated and alternate with gneiss and analogous rocks, do really contain an alkali; that their basis is a compact felspar, varying in composition, sometimes silica and sometimes felspar prevailing: it is probable that alkali may not be found in every specimen of this rock; for, sometimes, the clay-slate has assumed the character of a sedimentary rock by a partial decomposition which has altered its appearance, and may have removed the alkali without destroying the tenacity and structure of the slate: this state of things often happens in Cornwall, and is probably of universal occurrence.

But in offering to withdraw the objection urged against the transfusion of alkali through the primary slates, in the case of clay-slate, it is not intended to drop it altogether, but to claim its validity in the instance of quartz-rock, which, even in a state of considerable purity, and often in beds of no inconsiderable thickness, alternates not only with gneiss, but also with every member of the primary rocks. Let the appeal be made to the chemist, and by his answer let the question stand or fall. Can potassa or soda be transmitted through a mass of silica, whilst in a state of intense ignition, without entering into combination therewith? And if the temperature of the quartzose mass be so elevated as to permit the formation of a crystalline gneiss on its side most remote from the granite, and also to reduce its supposed primeval state of sandstone into a compact and crystalline quartz; would not the union of alkali therewith cause the whole to enter into a perfect state of fusion, and could it be expected to find in this mass of glass, when cooled, any trace of lines derived from stratification? It is unnecessary to add any further remarks to enforce the value of this argument; it speaks a plain and intelligible language, which cannot be misunderstood.

What shall we say, then? Are the objections which have been advanced frivolous, or are they sufficiently important to induce geologists to enter on a careful scrutiny whether the primary slates be really altered sedimentary deposits? If, indeed, there be any weight in the foregoing arguments, the primary schistose rocks are certainly not analogous to those altered portions of secondary rocks adjacent to trap and other igneous rocks; nor is the transition of these crystalline slates into fossiliferous strata indicative of a coeval formation: on what grounds, then, it may be asked, can it be demonstrated that the secondary rocks have been altered by granite, and converted into gneiss, mica-slate, and other primary schists? The importance of this subject claims a more particular consideration.

"The slates surrounding Dartmoor have been changed," says De la Beche, "by the intrusion of granite; some being simply micaceous, others more indurated and with the characters of mica-slate and gneiss, while others, again, appear converted into a hard zoned rock strongly impregnated with felspar. The alteration of the rocks in this case is of very easy explanation. The greywacké, which is for the most part the altered rock, is, when taken in the mass, only the consolidated detritus of more ancient crystalline rocks, composed of a few simple substances. If long-continued heat, insufficient to produce fusion, be applied to the ends of the greywacké beds, the various substances of which they consist would have a tendency to resume their original state, at least that state in which they existed in the crystalline rocks whence they have been derived; and, consequently, we should have compounds resembling various crystalline stratified rocks."*

Now, before this explanation can be admitted, it must be proved that the granite has been thus protruded through the strata over an extent of about twenty miles in diameter, and that crystalline slates, which once existed, have disappeared, after having provided materials for the structure of these metamorphic and unaltered masses of greywacké. It would be more consonant with reason to conclude that the fragments in the greywacké have been derived from the existing crystalline strata which they resemble, than to have recourse to rocks of which we have no knowledge, except through the medium of the Plutonic hypothesis: for such a proceeding is neither according to the general rules of induction, nor according to the acknowledged principles of geology, by which the relative ages of rocks are determined. Thus it has been observed by Lyell, that, "in investigating a district composed of two distinct formations, it is sometimes difficult to ascertain their respective ages, from want of sections exhibiting the order of their superposition. In such cases, another kind of evidence, of a character no less conclusive, can sometimes be obtained. One group of strata has frequently been derived from the degradation of another in the immediate neighbourhood, and may be observed to include within it fragments of such rocks; from which we may *confidently infer* that the group from which the fragments have been derived, is the oldest of the two formations."† Thus, "there can be no doubt that some granites are more ancient than any of our regular series which we identify by organic remains, because there are rounded pebbles of granite, as well

* Geological Manual, p. 479. † Principles of Geology, vol. iii. p. 36.

as gneiss, in the conglomerates of the oldest fossiliferous groups.*

But even conceding these points, it may be presumed that the debris, of which this fragmentary rock consists, was produced from the crystalline slates by causes similar to those now in action: turn, then, to decomposing primary slates (the supposed metamorphic schists, which are now interposed between the granite and unchanged greywacke), and it will be found that the oxide of iron contained in the perfect rock has become a peroxide, and the greater part of the alkali has disappeared from the argillaceous mass; and then explain how a degree of heat short of fusion could have reduced the metal to a lower degree of oxidation, and have restored the alkali to the felspar, in which mineral these crystalline rocks abound?

We are likewise called upon to admit that the Hartz furnishes similar evidence in favour of the metamorphic influence of the granite. Thus, according to M. C. Zincken, the strata of *hornfels*, which surround the granitic masses of the Ramberg and Rosstrap mountains, are, for the most part, igneous modifications of greywacké; the granite intersects these strata at various angles, and penetrates them in the form of veins, near which the laminæ of the slate are sometimes broken and bent, and fragments of the *hornfels* are imbedded in the granite: in short, the phenomena are such as commonly occur in Cornwall, and other countries, at the junction of the granite and slate.† According to this statement, it is supposed that granite has been violently injected among the strata, in a state of igneous fusion: but from the observations of Bonnard on the Hartz, of Brochant on the Alps, and of Von Buch on Norway, it might be concluded that the granitic masses of these countries are not distinct formations, being often regularly instratified with the adjacent schistose rocks, into which they on all sides gradually

* Principles of Geology, vol. iii. p. 359.

† Bulletin de la Soc. Géol. de France, tome iii. p. 32.

pass, and with which they are so intimately associated; that the slates sometimes completely envelope smaller layers or beds of the granitic compounds; and, *vice versâ*, the latter occasionally contain the former. Granting, however, the injection of the granite, it could not be the cause of the elevation of strata, which, as in the Hartz, underlie the granite on one side, and repose upon it on the other; nor could the granite of Mont Blanc have tilted up the adjacent strata, since it is only a crystalline variety of the talc-schist, similarly circumstanced as to position, being, indeed, analogous to the granite of Sweden and Norway, which is generally considered to be granitic gneiss. It may be argued that these elevations have been effected by concealed masses of granite, from which the injected portions have proceeded, and by which the metamorphosis of the strata has been effected: but this is only conjecture, and by such reasoning all difficulties may be as easily overcome; for it may be imagined that vast mountainous tracts once existed, which, after having supplied the materials for the immense masses of primary strata in the north of Europe, and other regions, were swallowed up, or in some wise obliterated by the elevation of the formation to which they had given birth. Ought such speculations to be preferred to the simple and self-evident induction, that secondary deposits, containing fragments of contiguous primary rocks, are more recent than the formations whence the detritus was derived.

The felspathic rocks of Cornwall are also adduced by Lyell, as the first example of the alteration of strata, in contact with granite: these various and beautiful rocks are called a coarse argillaceous schist, which is converted into hornblende-schist at its junction with the main mass, or with the veins of granite. If the dark-coloured slate sometimes resembles hornblende-schist, it, in numerous other instances, does not assume this appearance: and, even in the former case, we think that this name has only been applied for want of a better. So much, however, has already been said on this subject, that it is not necessary to make any further remarks: and, therefore, we will turn to those examples which more strongly illustrate the metamorphic hypothesis. The instance quoted by the same author, which occurs at Champoleon in the Alps, is very unsatisfactory in every respect: in the first place, the section does not appear to be natural, and the condition of the strata is not such as might be expected; we do not detect any of those changes of composition which indicate an analogy with the primary rocks; the argillaceous bed is only hardened, instead of being converted into hornblende-schist, or even gneiss; the grits are quartzose, and contain a thin layer of imperfect granite, and all this within a space only of thirty feet from ignited granite, which is capable, according to the theory, of effecting greater changes on beds far removed, and notwithstanding the intervention of an immense mass of bad-conducting substances. It is not impossible that in this case, since the granite at the junction is soft and not perfectly crystalline, it may be a derivative rock, as at Caithness in Scotland, gradually passing into the unaltered and untransported granite: but it is, perhaps, more probable that, as in similar cases, the nature of this rock may have been misunderstood; indeed, Studer has already observed that, "les apparences de Predazzo et de Valle Rabbiose, sortent pour ainsi dire de la ligne de celles qu'on peut appeler ordinaires, parce qu'elles se lient aux éruptions du porphyre pyroxénique, et il reste toujours quelque incertitude pour savoir si le granit de Canzacoli n'est positivement qu'une forme particulière de la roche pyroxénique." * The appearance of the stratified rocks, next the granite of Champoleon, is more analogous to that which is exhibited in the vicinity of dykes of porphyry and trap, than to that of gneiss, mica-slate, and similar crystalline rocks.

We are, however, informed by Hugi that, in the Alps, granite overlies fossiliferous limestones and slates, equivalent

* Bulletin de la Soc. Géol. de France, tome ii. p. 55.

to the more recent beds of lias, or the oldest members of the oolitic group; and that it has sometimes changed them into gneiss and mica-slate. This is more in point, and if satisfactorily proved would certainly be decisive of the question now under consideration; but, before the evidence can be received, it must be substantiated by the most minute and circumstantial details, in order that the train of reasoning by which this conclusion has been arrived at may be carefully scrutinised. We have already endeavoured to point out how little dependence can be placed on an apparent transition between the primary and secondary rocks, even when these are well exposed to view: and when it is remembered what different conclusions have been drawn from phenomena clearly displayed in the cliff-sections of the Cornish coasts, how difficult it often is to detect the real state of things, even under the most favourable circumstances, we may form some conception of the allowances that ought to be made for Alpine investigations. It may, perhaps, be considered by some that we are only starting a groundless and vexatious objection: but hear what Studer has said of this same geologist, when describing the connection of gneiss and limestone in the Bernese Alps: — "Il est singulier que M. Hugi ait mal représenté les faits dans ces lieux; car ni sa description, ni ses profils, ne coïncident avec la réalité, qui confirme cependant si bien ses observations dans ce Rothal." Again, De la Beche, after describing the phenomena of Jungfrau, as recorded by Studer, adds, that "we must here remark the uncertainty of many sections of this kind, however clearly the lines of separation may be exhibited on the face of a huge precipice, as this is; for it is well known to all accustomed to examine disturbed districts, where inconformable rocks have been tilted up together, that natural lines of section often cause a large mass of inferior rock to appear included in the superior beds, when, in fact, such appearance is entirely deceptive. This arises from a portion of the older rock projecting into the newer rock, having been accidentally cut through in the line of section."* "I spent some weeks," says Bakewell," almost close to the Jungfrau mountain, in the canton of Berne, and studied its structure with particular attention; and I have no hesitation in expressing a decided opinion that the section of M. Studer, representing two cone-shaped masses of limestone penetrating the granitic gneiss near the summit, is fallacious. The part represented as penetrated by the limestone is concealed by a covering of eternal snow." †

If we might be permitted to venture an opinion on the appearances at the Jungfrau, founded on the descriptions of the above-mentioned geologists, we should say that they are perfectly analogous to the gneiss formations of Scotland, Norway, and other countries. This gneiss abounds in magnesian minerals belonging to the talcose formation, which is often characterised by the peculiar granitic rock called protogine: it is generally lamellar, but in some parts massive, and there presents irregular concretions and veins of granite; so that, according to the proportion of these parts, the mass oscillates between granite and gneiss, though the latter prevails. The adjacent limestone abounds in talc and other minerals of this nature, and sometimes, by the intimate union of magnesia, it becomes dolomite; but the latter is not always in contact with the gneiss, so, as in the case of the dolomites of the Tyrol in contact with augite porphyry; it cannot be attributed to the influence of the accompanying rock on common limestone whilst in a state of ignition. Now, this crystalline limestone is the same as often occurs within gneiss, it only differs in position; and is in like manner subject to the same interference of veins or layers of gneiss, either lamellar or granitic. That this limestone graduates into the secondary rocks of a calcareous nature, so that it is difficult to say where the one begins and the other ends, is only in

* Geological Manual, 8vo. p. 457.

† Introduction to Geology, fourth edition, p. 101.

accordance with numerous facts which show that all the crystalline rocks thus pass into the mechanical or secondary deposits which have been formed of their detritus; and not only so, but even the unstratified and igneous granite exhibits a similar transition into stratified conglomerate and sandstone, without the intervention of any crystalline slate: facts which teach us that too much dependence must not be placed on this evidence as a proof of identity of formation.

The same reasoning is equally applicable to those cases in which granite is supposed to have converted the secondary strata into primary. The particulars of Hugi's examples, referred to by Lyell, are not at hand: but the instances of Glen Tilt in Scotland, and of the Eastern Pyrenees, detailed in the sixth chapter, may serve for the present.

In the first place, let us consider the metamorphosis which the strata are supposed to have undergone at Glen Tilt, in consequence of their coming in contact with granite. These strata are, various kinds of schist, limestone, and quartz-rock. The schists are clay-slate, hornblende-schist, talc-schist, and mica-slate, which in some places approaches near to gneiss; but these are not disposed in any fixed or determinate order: the hornblende-schist is often next the granite, but not always; the magnesian varieties are generally at some distance therefrom; and the mica-slate and gneiss, which ought as the most crystalline to be nearest to the agent of these changes, have been produced where the influence of heat must have been less energetic; whilst portions of slate near the granite have been, to use the prevailing phrase, altered in a less degree. The limestone at a distance from the granite is very crystalline, and either perfectly calcareous, or in some parts more or less blended with and variegated by magnesian minerals: the presence of magnesia is now generally attributed to the interposition of igneous rocks; but here, as frequently happens elsewhere, this is not always dependent on, or in proportion to, the proximity of the granite. On the contrary, at the junction of the limestone and granite, the former resembles hornstone or compact felspar, effervesces slowly, and contains a large portion of silica: how can this change be ascribed to caloric? It cannot be admitted that the limestone has been fused and combined with the adjacent granite, because it is stated that the lines of stratification are still preserved, though the strata are much dislocated and disturbed: and the chemist will not grant the possibility of carbonate of lime being converted by heat into silica. Again, the quartz-rock is in many positions nearly pure quartz even adjacent to the granite, whilst at a considerable distance therefrom, where the schistose beds are straight and undisturbed, this rock not only contains felspar, but is so disposed in conjunction with mica or hornblende as to form gneiss and even a perfect granite, and when this is the case the adjacent slate is intermediate between gneiss and mica-slate. How could granite have produced this change on a remote mass of quartz-rock, when that in its vicinity remains unaltered? How could the presence of granite cause the introduction of magnesia, alkali, and other elements, into distant strata, through rocks which are similar, and which may therefore be presumed to have an equal affinity for such elements.

Let us now turn to the crystalline limestones of the Pyrenees, described by Dufrênoy. He has concluded that the elevation of their strata, and their apparent gradation into the succeeding fossiliferous rocks, prove that they belong to the same mass, and that they have been altered and elevated by the adjacent granite. The changes here indicated are, a more crystalline texture, the presence of magnesia in the beds next the granite, and the abundance of iron-ores: the condition of its texture is only a character which this limestone enjoys in common with most primary rocks. The nature of the proof afforded by magnesia has been already considered; and the presence of metallic ores near the junction of granite is certainly in itself no evidence of the manner in which the containing rocks were formed. The questions of elevation and transition have been already discussed: as regards the latter, some might consider the line of disunion between the ferruginous limestone and the incumbent bed to form the boundary of the primary limestone: but much stress ought not to be laid on this fact; for it is more than probable that, though it occurs at many points it may not hold good throughout its whole extent. The beds of granite appear to this distinguished geologist to afford positive proof that the main mass of granite is more recent than the limestone. How can we otherwise comprehend, says he, the intercalation of granite between beds of dolomite, if the granite was not introduced after the manner of veins? According to the prevailing theory it cannot well be otherwise; and he therefore has concluded that these layers of granite are veins: but if this be admitted as a justifiable conclusion, then all the layers of granitic rocks found in the strata of gneiss, mica-slate, and clay-slate, and parallel therewith, are also veins, though we know by experience that these beds, in some cases, have no connection with the adjacent granite. Under all these considerations, it appears to us less objectionable to regard these limestones, with their granitic beds, and the main mass of granite, as members of the same primary formation, and connected with the fossiliferous limestones by mechanical transitions; and, although the line of union may be at present obscure, it may be hereafter detected by more minute observations, and nicer discrimination.

It must not be omitted to remark, that secondary rocks have been frequently found adjacent, and even in contact with granite, without exhibiting an altered or metamorphic appearance; and yet at the same time, by the inclination of their strata, indicating, according to the principles of the Plutonic theory, that they have been elevated by the protrusion of granite. Sedgwick and Murchison have recorded many examples of this nature, in the Transactions of the Geological Society, and have anticipated this objection, by supposing that the granite has been forced through the strata in a solid state. But in the north of Scotland, the phenomena are so various at different points, that, as already stated in a former chapter, sometimes the strata are concluded to have been broken, sometimes both the strata and the granite whilst in other cases the granite itself is shattered into fragments, the strata remaining uninjured; and, lastly, in some places the granite has produced crystalline slates, penetrated by granite-veins, indicative of interior ignition. These various appearances, however, are not so contiguous but that they might be imputed to numerous and distinct eruptions of granite: but even admitting this to hold good in Caithness and Sutherland, the same indulgence cannot be extended to the Isle of Arran, where the red sandstone reclines near the granite, in one place in an unaltered state, whilst, immediately adjacent, primary slates abound, containing granite-veins. And even if this objection should be met by supposing the same mass of granite to have experienced successive protrusions under different conditions, still it must be remembered, that these are only ingenious conjectures, suggested by the perplexing necessity of the case, and unsupported by any known effects of the internal igneous power now in operation.

In conclusion, we contend that the analogy between the primary and trap rocks is not perfect, the strata next the former exhibiting a chemical as well as a mechanical difference; and admitting the sedimentary strata to have been changed by the contact of trap in a state of ignition, a most perplexing difficulty arises, in the fact that the alterations are only partial: what could possibly have been the peculiar controlling circumstances which prevented a like cause from producing the same effects?

CHAPTER XV.

DO THE PRIMARY ROCKS AFFORD PHYSICAL EVIDENCE THAT THEY HAVE EXPERIENCED FISSURES, DISLOCATIONS, AND OTHER MECHANICAL MOVEMENTS?

The apparent indications of displacements. — The curvatures of rocks. — Alternations of curved and straight strata. — Veins often tortuous in straight beds. — The colouring ingredients of rocks arranged in undulating and contorted lines. — Similar appearances in agates and alabaster — also in igneous rocks. — Sir James Hall's explanation of curved strata. — The moving power imaginary. — The spheroidal structure of rocks. — Primary conglomerates not fragmentary — the secondary, sometimes mechanical, at others concretional. — Igneous and aqueous rocks also conglomerated. — Granite-veins — their structure and composition incompatible with theory — analogous to slate-veins — and to certain arrangements in crystalline rocks. — Mineral veins — different kinds of — veins of segregation in Cornwall. — Definition of true veins — objected to. — Intersections of veins no criterion of their relative ages. — Remarks on the heaves and other supposed movements of veins. — Conclusion.

The subject of this chapter has been in part anticipated in the discussion on the supposed elevation of the primary strata; and, certainly, on the determination of that question the nature of some of the phenomena about to be considered in a great measure depends; for these are generally presumed to be lesser movements, the concomitants of those vast catastrophes by which the stratified deposits of all ages were upraised from a horizontal position.

The effects, however, of these supposed subordinate movements present such varied appearances, and require to be combated by such different arguments, that their individual consideration cannot fail to elicit some instruction; and, indeed, unless they are passed under review, both by the supporters and the opponents of the prevailing theory, the discussion will not be satisfactory.

These subordinate movements are said to be indicated by the curvatures and contortions of the strata, and by the various phenomena exhibited by granite-veins, by dykes of porphyry, trap, and similar rocks, and by mineral and metalliferous veins. In the narrow limits of this work, these important topics cannot be fully detailed; it must therefore suffice to notice those facts only which bear more immediately on the question.

It is generally admitted that the layers of rocks may attain a certain degree of curvature, by deposition on an undulating surface, such as the exterior of the earth actually presents. But this cause has its limits, and is in no wise applicable to cases of complicated flexures and contortions, which so frequently occur in every country. These appearances were once thought to be confined to the older or primary strata; but it is now known that, though most frequent in gneiss and mica-slate, they do exist not only in every secondary group, but also in the tertiary formations. The precise manner in which these curvatures have been produced has given rise to much difference of opinion, though most geologists of the present day are agreed that, however modified by circumstances, they are ultimately to be attributed to the application of some moving power.

There are certainly many instances of curved strata which might possibly have originated from mechanical violence, provided these strata were, when bent, in a plastic or yielding state; but what evidence have we of the existence of such ductility in these rocks coeval with the application of a moving power? and, in examining this question, let us confine our attention to the primary rocks, a restriction which is most favourable to the supporters of this opinion.

It is presumed that the advocates of the Plutonic theory will not select the period of deposition, when gneiss and mica-slate are supposed to have existed as unconsolidated sediments, but would rather adopt the metamorphic stage, whilst the primary schists were in a state of intense ignition by the contact of melted granite; the protrusion or lateral extension of which is the adopted cause of the bendings and flexures of the gneiss and mica-slate. Now, without stopping to enquire which mode of motion is the more probable, — whether that previous to, or that attendant on, the elevation of these strata from a horizontal to their present elevated inclination, — let it be admitted that these concurrent conditions of plasticity and motion (which we have already contested) have effected the curvatures of these rocks. If this be the case, how then has it happened that one stratum, or a series of strata, is regularly curved at one point, and yet is broken off abruptly at another; or, to speak more correctly, terminates abruptly. This is of frequent occurrence; but, what is more to the purpose, the apparent fracture and flexure may be sometimes witnessed at the same point of curvature; several examples of which have been recorded by Macculloch, but one remarkable instance, in particular, which he saw in Lunga, one of the Western Isles of Scotland, and which he has attributed to the modified action of the moving power, operating on strata of a different nature, the associated rocks consisting of alternating layers of argillaceous schist and quartz-rock. "Where the flexure is very acute, the quartz-rock is broken, while the schist is only bent; and, in some extreme cases, fragments of the former are separated and entangled among the latter; facts speaking a language that cannot be misapprehended." * A different view, however, may be taken of this phenomenon, and it may be interpreted into evidence unfavourable to the conditions of plasticity and motion; for if the whole were softened, how came it to pass that the quartz-rock was "urged beyond its power of flexibility?" Because, it may be answered, the quartz-rock and the argillaceous schist possessed different degrees of hardness. But this is a mere assertion; we do not know that the latter is more fusible than the former, on

* System of Geology, vol. i. p. 115.

the contrary, indeed, many kinds of this schist are equally, if not more refractory in the furnace: but supposing the quartz-rock to be less susceptible of being softened, how does it happen that in other parts of the same series of rocks, the quartz-rock partakes of every degree of flexure and contortion; and even pure quartz, in the form of veins of various size, is very commonly seen traversing not only clay-slate, but also gneiss, mica-slate, and other primary schists; and "following the sinuosities of these rocks, however intricate, without any fracture or breach of continuity." Surely, then, if quartz-rock can be bent and contorted, at such a temperature as attends the metamorphosis of sedimentary deposits into crystalline slates, or as is required to render the whole mass of these slates soft and ductile, it cannot be admitted that the appearance under consideration is a proof of fracture. But even if this objection be not allowed, another immediately presents itself, which is indeed of an analogous nature: what we have just seen to occur in the layers of a single curve composed of different rocks, we find, on the large scale, to extend over considerable tracts; thus, immense beds of contorted rocks alternate with those which are comparatively straight and regular, and this holds good whether the whole mass of strata is highly inclined or nearly horizontal, that is, according to the prevailing opinion, whether it has been broken through and tilted up at a considerable angle, or has been undisturbed. The description of an occurrence of this kind in the Pyrenees, by Duhamel, as quoted by Greenough from the Journal des Mines, clearly shows the different manner in which parallel strata have been arranged: "Compact felspar, trap, and limestone there form an immense mass, composed of a prodigious number of alternate beds of no great thickness, and inclined to the horizon at a high angle: some of them are plain and regular, while others are twisted in a thousand different directions, without disturbing the parallelism of the beds above or beneath." *

* The First Principles of Geology, p. 62.

We have also noticed a similar fact in the northern part of Cornwall; the strata are arranged in regular undulating curves, but parallel with each other; some are composed of straight, others of curved and twisted laminæ, exhibiting the most intricate contortions.

How can these facts be explained on the grounds of mechanical violence? for how is it possible that some strata could be soft and others not, some bent and twisted, whilst others give no indications of any forcible derangement: and yet all these strata (if metamorphic) have been exposed to the same igneous action, and all (whatever their nature) have been subject to the same moving power, since they alternate with each other in parallel beds? This is no new objection; the same has been often urged by those who have contemplated the various anomalous arrangements of contorted strata, arrangements which "cannot be explained by supposing the beds to have been regularly deposited in the first instance, and shifted afterwards by subsidences, shocks, or convulsions."

In addition to the anomalies above mentioned, it may be stated that the contemporaneous quartz-veins (which sometimes follow all the intricacies of the curved strata, and at others traverse these curves in some places, and are parallel thereto, in others, as if of a later origin) are occasionally found running a most serpentine and tortuous course through mica-schist and other primary slates which are regularly arranged; for instance, at Tremearne, near Trewavas Head, in Cornwall, in the vicinity of the junction of the slate and granite, the former rock is traversed by quartz-veins under these circumstances; and Macculloch has observed "that veins of quartz sometimes occur in gneiss, which are most intricately contorted, although the laminæ of the including rock show no corresponding indications of flexure." And he adds, "this is a difficulty which, among a thousand others, must remain for future explanation; and how far its solution may modify any of our theories, it is impossible at present to foresee."* The same indefatigable geologist has furnished us with another anomaly in the exhibition of curvatures on the surface of an artificial cliff in the slate, at the back of the gun-wharf, Plymouth; these curvatures are formed by a number of dove-coloured stripes of unequal thickness, which traverse a faint brown-red ground in very irregular curved lines, bearing a sort of parallelism to each other; in short, resembling strongly a piece of marbled paper. "The continuity of the lines of colour precludes all possibility of a succession of deposited layers otherwise than in those very lines, and affords at the same time a proof, if any were wanting, that the fissile property of the slate has not been the result of stratification."† And appearances of the same nature are very common on the surface of the laminæ of several kinds of Cornish slates, and more particularly of those which belong to the intermediate or transition series, and which abound in veins and deposits of manganese ore.

Some varieties of shorl-rock (both in the granite and in the slate), of actynolite-rock, and of other unnamed rocks belonging to the slate group of Cornwall, abound in contorted appearances which somewhat resemble the preceding, but are not perfectly analogous, depending on the manner in which their constituent minerals are respectively combined: thus, in the shorl-rock, the quartz and shorl intimately united, exhibiting various shades of black and dark blue, alternate with portions in which the shorl is wanting, and consequently consist only of white quartz; and these differently coloured parts present, throughout the whole rock, and in every direction, the most intricate contortions, perfectly resembling those so common in mica-slate. These rocks are generally compact or massive, and their cleavage may be effected with equal facility either across or in the direction of the curves: but

* System of Geology, vol. i. p. 119.

† Geol. Trans., vol. iv. p. 399.

when this contorted structure occurs in schistose rocks, the laminæ are often found to correspond with the flexures, and consequently they are fissile in the same direction.

It is, therefore, no easy matter to determine where the line is to be drawn between these different kinds of curvatures, so as to separate those which are supposed to have been produced by the application of force to rocks in a soft and ductile state; for, indeed, they are so connected one with another, and assume such identical forms, that one is a perfect representation of the other in miniature.

If this be admitted, another step will lead us to the waved and marbled delineations in agates and alabasters: and then the conclusion irresistibly forces itself on us, that all these internal contortions of every degree and size, whether of the whole or any portion of a rock, may be referred to a peculiar mode of concretionary structure, how difficult soever it may be to conceive by what means it was produced.

On this view of the subject, the same kind of structure might be expected to occur in granite and other igneous rocks, that is, in the very agents themselves to which the curvatures of the stratified rocks have been attributed: for it has been shown that the same laminated, schistose, and tabular structures, are common to rocks both of igneous and of aqueous origin; and, if these different modes of structure are independent of the nature of the rock's origin, and only to be ascribed to the modified operations of the attraction of cohesion, by which the incoherent particles of the rock were consolidated, the igneous rocks ought also to exhibit curves and contortions. And so they do; this theoretical deduction is borne out by an appeal to nature. Wherever a good section of granite is exposed in a cliff or quarry, we shall find that the parallel lines by which this rock is intersected, though having a regular bearing, like the curved strata when viewed along a line of considerable extent, are very seldom perfectly straight, but are more or less curved; and this obtains not only with the horizontal, but also with the perpendicular joints of the granite: and all the large veins which traverse this rock generally run in a serpentine course. These appearances are beautifully displayed near Mousehole at the Logan Rock, and in other parts of the granitic districts of Cornwall.

No advocate of the Plutonic theory would offer to explain all these phenomena by a mechanical agency: but they appear to be so nearly allied to each other, that it would be no easy task to distinguish those that have been violently formed from those which could not have had such an origin. Take, however, the most favourable of these examples, the primary slates, and, even admitting that granite has been protruded, how and when were their convolutions effected? These are generally referred to the elevation of the granite. Sir James Hall advocated this opinion, though he candidly confesses, that he "has not been able to discover any case in which it has performed this function, all the junctions bearing marks of an infusion of the liquid granite into hard and brittle strata." "The scenes in Galloway," he adds, "prove that the granite has been more recently formed than the contorted slate; but they prove over-much in one respect, since they show the arrival of the granite at its present place to have been posterior, not only to the formation of the strata, but also to their convolutions when in a state of softness, and to their subsequent consolidation." He therefore concludes, that the existing granite has not produced this mechanical effect, but some unknown mass of granite, acting at some unknown time antecedent to the elevation of the strata.*

By such arguments as these the violent formation of convoluted strata is still maintained: their fallacy, however, is too obvious to need farther comment.

The curvature of the layers of the unstratified rocks, both on the large and small scale, appears to be intimately con-

* Royal Trans. of Edinburgh, vol. vii. p. 98.

nected, if not identical with, the spheroidal structure so generally observed to prevail in granite, and in the various porphyries and traps. It is not always very evident, but is generally developed in the individual concretions of these rocks by disintegration; and is often conspicuous on a large scale, in the round-backed form of hills which are entirely composed of such rocks.

Now some may contend, that even these appearances may have been produced by force applied to these rocks whilst in a state of semi-fusion. If, however, any power has influenced this arrangement, it is probably only such as might arise from the expansion and movement of the parts during crystallisation or consolidation; a force very different from that which is supposed to have deranged the laminæ and strata of the sedimentary rocks.

On all these considerations, therefore, it may be concluded, that the various curved appearances which rocks present, are not certain indications of their having been subjected to mechanical violence; on the contrary, that they are not incompatible with the effects of the power of cohesion by which the rocks were consolidated.

This opinion has been entertained by many geologists; and amongst others, by Mr. Weaver, who, after a careful examination of the inflections and contortions of the rocks in the east of Ireland, considers that these peculiar arrangements have not been produced by violence; and concludes, that these appearances, as well as the stratified structure, in all its varieties, result from concretion on the large scale.*

The spheroidal structure brings us to the consideration of the brecciated and conglomerated appearance of some rocks, which have by many geologists been regarded as sure evidence of a mechanical origin.

It must not for a moment be imagined, that we are about to contend that all breccias and conglomerates are not frag-

* Geol. Trans. vol. v. p. 175.

mentary and derivative rocks: such a position would be absurd, and contrary to positive evidence. But it is proposed to enquire, whether the resemblance to fragments and pebbles observed in many primary, and indeed in some fossiliferous rocks, may not be only a sportive imitation of nature, a coincidence more apparent than real, and capable of being referred to a cause distinct from that by which the materials of the mechanical rocks were produced.

Let us begin with the more simple case of the conglomerated appearance: and it is necessary that the general reader should reconsider the details already given on the structure of rocks.

In the preceding chapters we have endeavoured to show, that the crystalline strata are not sedimentary deposits, subsequently altered by Plutonic agency; but the occurrence of these conglomerates, interstratified with such strata, may appear to be opposed to this conclusion; at least it is viewed in this light by the most eminent geologists of the day. We, however, appeal from these authorities to nature; and maintain, that the nodules of these conglomerates, generally, if not always, possess characters very different from those which occur in true detrital deposits. The latter often consist of various substances, some of one rock and some of another; exhibiting different forms, according to the nature of the fragments from which they have been formed; and all these occur in a basis which has seldom the same composition as the included nodules. The former, however, are of a similar nature in the same rock; and in their constitution partake of the elements not only of the adjacent strata, but also of the basis in which they are imbedded; and very frequently their component parts are arranged around compact or crystalline nuclei; sometimes, indeed, so regularly, as to assume a perfect concentric structure. Thus, in the case of gneiss, it often happens that the nodules and the basis can only be distinguished from each other by the globular structure of the former; or, if they differ in composition, as in the Isle of

Coll, where the central part of the nodules consists of hornblende-rock, this difference can be explained without considering that these nuclei have been derived from fragments of the latter rock; for the characteristic mineral of this gneiss is hornblende; and that it has been attracted to certain centres, and there formed by its predominance a hornblendic rock, is in perfect accordance with the patches or concretions which occur in granite, and all the primary rocks: and it must be remembered, that insulated nodules, patches, short layers or veins, and other irregular forms of the hornblende-rock, are characteristic of the adjacent strata of gneiss; the conglomerated stratum only differing from their concretions, by being so abundant as to prevail over the ordinary structure. Again, turn to the description of the conglomerated mica-slate of Drontheim; its nodules are also formed of the same constituent parts as the containing rock, but they exhibit a different texture, owing to their mode of aggregation: the mica is intimately diffused throughout the schistose basis; but in the nuclei of the nodules it is in a great measure wanting; thence their compact structure, and, as if to compensate for this deficiency in the nuclei, it predominates in the micaceous laminæ by which the nuclei are concentrically enveloped. And the structure of the conglomerated chlorite-schist of Relistian is very analogous to that of this Norwegian rock. But it may be argued, that it frequently happens that these conglomerates are formed of quartz-nodules, as is also the case with similar rocks in secondary formations. It does so: but if the former be minutely examined, it is very probable that their nodules will exhibit characters incompatible with a mechanical origin, such as the penetration of them by one or other of the constituent minerals of the containing rock; as in the case of the schist in the Cotentin, where talc is blended with the quartzose concretions, as described by Brongniart; who considered it a proof that the nodules were formed contemporaneously with the strata in which they are enveloped: or the nodules themselves, by their occasional irregularity of form, will indicate an intimate connection with the basis, as in the rock of Cronebane, recorded by Weaver, in which they are extended in thin edges between the laminæ of the stratum; a disposition and form certainly not indicative of violent attrition.

It may, however, be farther urged by the advocates of the Plutonic theory, that the secondary rocks also exhibit examples of nodules and bases possessing a similar composition, and in which the nodules have the same kind of concretionary structure. Such cases have been recorded: we have noticed one at Crackington Cove*, on the north coast of Cornwall; its nature is not positively determined, but it probably belongs to the same series as the dunstone and dark limestones of Devon, and is therefore a fossiliferous formation of the oldest description. But we cannot admit this as evidence that these rocks are of mechanical origin; it does not follow, because this conglomerate is situated in a sedimentary deposit, that its lenticular concretions have been produced by transportation and attrition: it only indicates that such nodules may sometimes result from the peculiar aggregation of the particles of rocks during their consolidation, whether of aqueous, igneous, or any other origin, just as the same cuboidal, prismatic, lamellar, schistose, or other kinds of structure may have originated in all rocks under similar circumstances: all that is requisite for such an arrangement is, that the integrant particles have the necessary degree of motion among themselves during the lapidification; but the manner in which this is attained does not appear to be material. We are borne out in this conclusion by the fact, that supposed igneous rocks possess the same kind of conglomerated structure as stratified rocks; as shown in Macculloch's sketch of the decomposing granite in the Isle of Man†, and also by the occurrence of the same arrange-

* Geol. Trans. of Cornwall, vol. iv. p. 178.

† Western Isles of Scotland, pl. xxviii. fig. 3.

ment in trap. In Pembrokeshire, says De la Beche, "besides the above-mentioned varieties of trap, there occurs one which has the appearance of conglomerate. The base is a black and very compact trap, which contains grains of quartz, and seeming fragments of crystallised felspar and of compact felspathic cornean. It is probably, however, a pseudo-conglomerate, or concretional rock, originating in a peculiar and contemporaneous aggregation of its constituent parts." * And of the same nature are the orbicular granite and porphyry of the island of Corsica, and the trap rocks around Edinburgh and in other parts of Scotland; and surely the globular structure of neither can be attributed to mechanical action. So likewise the spheroidal and concentric arrangement of the laminæ in the sandstone at Dunbar, which is referred to the influence of ignited trap, but which, however effected, has probably been superinduced since the accumulation of the original incoherent materials of this sandstone; for we cannot suppose that these spheroids have been formed by attrition; and such an origin is still less applicable to the concentric globules in the travertin of Trivoli, and in similar tufaceous rocks, which are in a state of constant and progressive deposition from calcareous waters.

The brecciated appearance of some primary rocks can rarely, if ever, be confounded with that of true fragmentary formations; for one or other of their ingredients will be found assuming such delicate or intricate ramifications as cannot be reconciled with a mechanical origin. It is true that this may not be visible in every specimen, but it cannot fail to be observed when these rocks are examined on a large scale: and farther, the ingredients will commonly be found, here and there, gradually passing into each other by mineral transitions. It is very probable that cases have been observed in which the same characters are possessed by secondary rocks; but this would not be any objection; it would

* Geol. Trans. (New Series), vol. ii. p. 3.

only render it probable that the brecciated, like the conglomerated, structure may occur in rocks of every description, being perfectly independent of the modes in which the materials of such rocks were produced and accumulated.

Having enquired into the nature of the angular and globular concretions of rocks which impart a fragmentary appearance, we are the better prepared to enter on the examination of the phenomena at the junction of granite with slate:—here also we shall find occurrences of a similar nature in the detached portions of granite and of slate which are respectively enveloped in the main mass of each of these rocks, but they are farther complicated by the presence of granite-veins traversing the slate; a convincing proof, according to the prevailing theory, that the latter rock has been rent and fissured by one or more convulsions.

Granite-veins are supposed to belong to different periods, because they sometimes intersect each other; and it is presumed that the oldest must be those that are connected with and are in continuation of the main mass of granite, because they appear to have been formed at the time of the protrusion of the granite through the slate in a state of igneous fusion; whilst the newer ones must be those which not only traverse the slate, but also penetrate the granite in a distinct and regular course, indicating that they have been injected since the consolidation of the granite. But even on this simple view of the subject, and admitting that the slate, in a soft and yielding state of semi-fusion, could have been broken and separated in every possible direction by a mass of melted granite, so that in some instances, as at Cape Wrath, in Scotland, the veins should far exceed in quantity the stratum that is penetrated; yet, even after every allowance of this kind, it is difficult to explain the fact, that the individuals of each set of veins not only intersect and heave each other in the most promiscuous manner, but the same thing happens between the veins of distinct kinds. Again, we not only find granite-veins within granite, intimately connected with this rock, at some points, by mineral gradation, but also, as at the Logan Rock, in Cornwall, united by large crystals of felspar, which are imbedded partly in the granite and partly in the vein; and, in like manner, the granite-veins in the slate, though frequently divided on each side by open lines or seams, resulting from the action of the elements, yet, in very many instances, the vein and the slate adhere so strongly together that they cannot be accurately separated by the hammer; and appear to pass so gradually into each other, that a difference of colour is the only distinguishing character; and even this is sometimes, as at the junction of the main mass of granite and of slate, so indistinct that we cannot see where the one begins and the other ends. Not only so, but the vein and the slate exhibit the same phenomena at Bunawe, in Scotland, as the vein and granite do at the Logan Rock. "Although the granite-veins," says Macculloch, "sometimes run through the schist in a distinct form, just as they do in the junction of Loch Ranza, yet in many places they are intermingled with it in the most remarkable manner; crystals of hornblende may be observed shooting far into the body of the schist, so as to render it often difficult to assign the limits of each rock, and in a less degree, the quartz and felspar of the veins exhibit the same appearance." *

Now these facts do not proclaim the disturbance of a sedimentary rock by another of a totally different nature; they rather suggest the idea that these rocks are of a similar composition, and have been formed in the same manner. In the case of granite and gneiss this suggestion would not appear so startling, but in the case of granite and slate it carries an air of absurdity, according to the notions generally entertained of clay-slate. Let us, however, instead of using a term so indefinite as clay-slate (and so inappropriate, as far as the Cornish schistose rocks adjacent to granite are concerned), rather regard these slates as compact felspars,

* Geol. Trans. vol. iv. p. 120.

united with small and variegated portions of mica, shorl, or hornblende, which are commonly equably diffused, imparting colour to the slates; and the compact felspar, since it contains more silica than crystallised felspar, may be looked on as an union of felspar and quartz. On this view, both the granite and the slate have a similar composition, differing from each other only in the proportions and in the mode in which their constituents are combined, so that it matters not whether the strata be gneiss or clay-slate in contact with the granite; it is equally easy to conceive these various appearances to have arisen from the peculiar arrangement of the constituent parts during combination. Let us turn to the various felspathic rocks which exhibit light and dark-coloured stripes, and these will often be found to display the most intricate flexures and wavings; and also sometimes the light, and at others the dark parts, will be seen ramifying and intersecting each other precisely in the same manner as the granite and the slate; and in the variegated marbles and serpentines appearances somewhat similar may also be observed; and yet in none of these cases can it be supposed that the veins and the bases have had a distinct origin.

It is true that in these examples the rocks are of a more simple composition, and therefore we do not find such great contrasts as in the associated granites and slates; but this cannot be a serious objection, since we not only find the different kinds of granite in a state of union equally abrupt, and also the various crystalline slates similarly circumstanced; but in the middle of a block of granite, far removed from the schistose group, the constituents are oftentimes so arranged, as not only to resemble angular portions of hornblende-rock, shorl-rock, and porphyries, but also of gneiss, mica-slate, and felspar-schists. Are we not taught by this, that what has been produced on a small scale may have happened over more extensive tracts. These small rays of light, however, do not alone illuminate this interesting page of nature, but others, gradually increasing in splendour, conduct us step by step, until the characters become perfectly legible, though they may be misinterpreted. Thus, in the mountains of Benna-vear, near Balahulish, at Loch Ranza and Loch Spey, and in other parts of Scotland, described by Macculloch, angular portions of various kinds of slate (as micaceous, hornblende, and argillaceous schists, gneiss, and quartz-rock) occur in the granite, insulated and far apart in some places, and in others equalling in quantity the granite, which seems only to form a connecting paste or basis; and this again is succeeded by the respective slates, in which the granite is wanting excepting in the state of veins and subordinate masses.

Perhaps it may be contended that this fact indicates that these slates were shattered and detached into angular portions by the invasion of melted granite: admitting, however, that such fragments of slate could be thus detached, and preserved in insulated positions by the rapid cooling of the granite in the interstices, yet, when we leave the junction of the granite and slate, and proceed within the granite, numerous difficulties assail us at every step. How could the small portions of slate which there occur retain their accurately truncated and angular forms when involved in intensely heated granite far exceeding in bulk the included fragments? By what counteracting principle have like causes been prevented from producing like effects? Why did these slates escape fusion when exposed to heat equal to the melting point of granite? since one of them, the hornblende-schist, will fuse before the jet of a common blowpipe; as will also the primary clay-slate, if more felspathic than quartzose. Again, it may be enquired how these portions of slate could have escaped the perfect metamorphosis which is attributed to the most elevated temperature? Gneiss, this theory asserts, is more schistose and distinctly stratified at a distance from the ignited mass of granite, but, as it approaches thereto, it becomes more crystalline, until at last the lines of stratification are nearly obliterated, and it becomes granitic gneiss not to be distinguished mineralogically from true granite. If this state of things be dependent upon the heat to which these strata have been subjected, how came it to pass that the angular portions of gneiss could have escaped fusion and an assimilation to perfect granite, when placed not only in contact with, but absolutely enveloped in a mass of melted granite? In like manner, how could the clay-slate preserve its identity, when we are taught that it is converted into hornblende-schist by exposure to an elevated temperature?

We will not, however, enlarge on this topic: many other inferences are so obvious that they will readily suggest themselves: it remains to know whether these objections can be satisfactorily explained.

To return to the granite-veins. Do they always proceed from the granite, gradually tapering away in such a manner as fissures might be expected to do if produced by the forcible protrusion of a large mass through the stratified rock? It has been stated that they exhibit no uniformity either in their size or mode of arrangement; they proceed from the granite in every direction, underlie at every angle, and, in their course, become larger and smaller in the most disorderly manner; and not only so, but even when comparatively regular, and a foot in thickness, they are often found to terminate in minute strings before they reach the exposed part of the mass from which other veins are given out. These veins also may be frequently seen, not only in the granite, but also near the junction, and even in the slate entirely, at a considerable distance from the granite, varying both in length and thickness, and terminating at both ends either abruptly, or gradually diminishing to a mere thread. When veins of this description occur wholly in the schistose rock, far removed from the granite, they can scarcely be supposed to have proceeded from the latter: thus, the innumerable granite-veins that are completely enveloped in gneiss and mica-slate, could not possibly have had such an origin; nor the short venous portions and irregular masses of granite which are similarly situated in clay-slate, and which, as in the gneiss and mica-slate, are so closely blended therewith as to pass imperceptibly into each other. Sometimes, indeed, these rocks are variously intersected by quartz-veins, which every one would pronounce to be contemporaneous, and yet these often assume a compound crystalline character, and in some parts perfectly resemble the granite-veins. And it must also be observed, that when granite-veins attain a foot or more in thickness, the open seams traversing the containing rock, dividing the mass into concretions, often pass through the veins, giving rise, when the concretions are detached, to fragments or blocks which consist partly of slate and partly of granite: precisely as happens at the junction of the main masses of granite and slate, when these have not been separated by seams of structure coincident with the line of union.

In short, the granite-veins put on such an endless variety of appearances, as to size, length, and number; and sometimes interlace and reticulate the schistose rock in such a complicated manner and so profusely, that the whole mass appears to be a congeries of these veins, the basis, as the gneiss at Cape Wrath, forming but a small portion of the whole: so that it can be compared only to the venous appearance of a thickly mottled and variegated marble. This fact alone ought to lead us to suspect, that probably these veins have not resulted from the injection of granite into the fissured slate. We have, however, been so long accustomed to consider that all veins were once fissures, and that all portions of rock that have an elongated form or structure are veins, that it requires no little effort to prevent ourselves from jumping immediately to this conclusion, whenever we meet with such appearances. And yet we know that it has been frequently stated, that even sandstones, gypsums, and other sedimentary deposits often exhibit forms which, in the primary rocks, would be denominated veins. Professor Jameson has repeatedly pointed this out; and Dr. Macculloch has also recorded some appropriate examples. After having described the mutual interference of limestone and schist with each other at Gow's Bridge, in Glen Tilt, he remarks, that "it is evident, that both the prolongation of the limestone and that of the schist bear a great resemblance to the veins which, in the case of granite, may be traced from a mass of that substance into the neighbouring rocks: yet there is no doubt that both these rocks are stratified. I have observed the same appearance in clay-slate, and it is frequent in the islands of Scarba and Jura, where this substance alternates with quartz-rock, and where both rocks are greatly contorted. A more remarkable example occurs in a rock which constitutes one of the numerous beds of which Schihallion is composed. This rock is a mica-slate, containing imbedded fragments of granite and of quartz-rock, often of considerable magnitude. The larger fragments of quartz-rock are sometimes partially split at right angles to its lamellar structure, and these fissures are filled with the substance of the mica-slate, putting on the same pseudomorphous appearance of a vein. I have found similar veins of red sandstone in the limestone of Arran, and they have also been seen in trap: thus, at Kinnoul, greywacké schist is prolonged into ramifying veins in the interstices of a trap rock by which it is broken and disturbed.* And, lastly, the contortions of argillaceous schist in Isla are very great, and sometimes they are elongated into the body of the quartz-rock: — "The appearance is so like that assumed by veins, that it is not surprising if it has sometimes misled observers."† Now we frankly confess that, in this case, as in that of discriminating between the layers of granite and the strata of primary slates, we have not only lost our way, but cannot discern it even when thus pointed out; for we have looked again and again, and cannot perceive that Nature has made any distinction between granite-veins and slate-veins; we can only see, in this peculiar form of matter, elongated por-

* Geol. Trans., vol. iii. p. 279.

† Western Isles of Scotland, pl. xxii. fig. 5.

tions of the respective rocks, — which may be either connected therewith, or entirely insulated in the traversed mass.

That slate-veins have not been more frequently observed, may be attributed to their generally possessing the same colour as the containing rock, on which account they are not easily distinguished; and also to such veins having a compact structure, similar to the massive varieties of rock abounding in each primary slate, and which, as has been already stated, only differ from each other in structure, being species of the same genus.

The apparent movements which intersecting granite-veins exhibit have been adduced as a proof of the mechanical origin of these veins: we will not, however, consider this subject at present, as we shall shortly discuss the nature of mineral veins, in which precisely the same phenomena are more clearly developed. We will, therefore, conclude this topic with Dr. Macculloch's very interesting remarks on the arrangement of the minerals which constitute the granite of Portsoy; he considered it necessary to apologise for entering into such minutiæ, but we do not hesitate to quote the passage at some length, as it appears to bear with no inconsiderable weight on the subject under discussion.

"The singular disposition and mutual relations of the crystallised substances which form the granite of Portsoy are known to have afforded to Dr. Hutton an argument for its igneous origin; and its peculiar character (called graphic) has been supposed to arise from a simultaneous, or nearly simultaneous, crystallisation of the several substances contained in it. The specimens about to be enumerated are such as not only throw considerable doubt on this explanation, but are in fact sufficient to prove a sequence of epocha even in this limited space, and to show that the compound rock in question has been formed by successive operations, the nature of which, however, I fear we shall not easily determine." "In one of the specimens a detached crystal of shorl, of a flattened and irregular figure, has been broken into four parts, by transverse fractures, which have again united without the intervention of any intermediate substance. Previous to this reunion, however, they have been slightly shifted, in such a way that the several parts of the fractures project, and the whole crystal has undergone a slight deviation from its original straight line. If it be alleged that this appearance could arise from a disturbed crystallisation, the next specimens will remove any doubt on this head. In these, the crystals have not only been fractured in the same way, across their axes, but the fractures are filled by the quartz and felspar, which constitute the body of the rock. The granite-veins of Arran do not show more clearly the ramification of a central substance through the fractures of the neighbouring rock, than these specimens show the veins of quartz proceeding from the mass, and penetrating every fissure which had been formed in the crystal. It is perfectly evident that whatever is true of the above cited granite-veins must also be true of this rock, that the shorl has been crystallised, then broken, and penetrated by quartz in a state of fluidity. Nor is there any intermixture of the matter of quartz with the matter of shorl, but the line of separation is most accurately drawn between them. It follows then from these circumstances, that the rock in question is not a simultaneous formation from a state of fusion, nor can we readily understand how it can be the effect of fusion at all, consistently with the chemical principles we acknowledge. Had such a mass of fused quartz invaded the minute fragments of shorl which the specimen exhibits, the latter must either have been formed into a shapeless mass, or at least the asperities of fracture could not have remained in a substance whose fusibility is so much lower than that of quartz. To those who attribute the formation of this rock to aqueous solution, it may be objected that the crystals of shorl are sometimes bent without fracture, so as to form considerable curvatures. The noted fragility of shorl will not allow us to suppose that it could be bent without breaking, unless it had been previously rendered flexible by some chemical agent possessed of powers which we have not hitherto discovered in water." * We shall hereafter revert to this curious subject: but it may be now observed that this interference of one crystal with another, in a compound mass, is not uncommon, though seldom so distinctly displayed as in the Portsoy granite; indeed, any large grained variety of granite, if minutely examined, will be found to afford some examples of this phenomenon.

The general opinion concerning the nature of veins is, that they are of three kinds: 1st. Those which are referred to an igneous origin, such as injected and sublimated veins. 2d. True veins, or such as were originally open fissures, but subsequently filled by chemical or mechanical depositions from water. 3d. Contemporaneous veins, or such as seem to be coeval with the aggregation of the component particles of the rocks in which they occur. The last mentioned are now often called veins of segregation: a term introduced by Professor Sedgwick, at the suggestion of Mr. Whewell, to express that they have been formed by a separation of parts during the gradual passage of the mineral masses into a solid state.

Now if any veins of this character occur in Cornwall, we may commence with them as a fixed point with which our subsequent observations may be compared. "In all the crystalline granitoid rocks of Cornwall," says Professor Sedgwick, "there are many masses and *veins of segregation*. Such are the great contemporaneous masses and veins of shorl-rock; and some of these are metalliferous. The decomposing granite of St. Austle Moor is traversed, and sometimes entirely superseded, by innumerable veins of this description. Upon these lines of shorl-rock, there is often aggregated a certain quantity of oxide of tin, which sometimes diffuses itself laterally into the substance of the contiguous granite.

* Geol. Trans., vol. ii. p. 432.

After examining this district with Professor Whewell during the summer of 1828, we left it, in the conviction that several of the neighbouring tin works were opened, not upon true *lodes*, but upon *veins of segregation*."* These remarks of the Professor were called forth in noticing Mr. Weaver's observations on the metalliferous veins of the south of Ireland: viz. that the copper ore sometimes occurs in *true veins;* and, at other times, is very generally diffused either in separate particles, or in strings, veins, and filaments, more or less connected with each other, but not continuous, and therefore contemporaneous with the rocks to which they are subordinate. Now this is precisely the condition of both copper and tin ores in Cornwall; for they are never in that country arranged "in great vertical dykes of metallic ore," as seems to be the common opinion, but in grains and in globular and angular portions of various forms and dimensions, or in layers, veins, and strings, completely insulated either in the quartzose part of the veins, or in the rocks, whether granite or slate, whether enveloped in angular masses, or *horses*, in the veins, or connected with the main mass in which the veins are situated. If, then, such a disposition of the ores be an indication of segregation, all the metallic minerals of Cornwall are referrible to this mode of production. And since the metalliferous veins of St. Austle Moor are admitted to have had a similar origin, in what respect do they differ from those in other parts of the county? Some may say that they are shorter than true veins, and may be generally seen terminating in length and depth: this may appear very plausible, but will not bear the test of a rigid examination. It is true, that innumerable veins in this district answer to this description; but it is no less true, that, between the smallest of these, and the large regular lodes of the adjoining mines, which have not been *outworked* in length or depth, there is a regular gradation as to size: so that no characters have been detected

* Philos. Mag. or Annals, vol. ix. p. 284.

by which they can be distinguished from each other. Nor does the difficulty terminate here. It has been asserted, that such veins of segregation abound in granite; and it is likewise well known, that veins, having precisely the same appearance, are frequently found in the slate; and when they are very numerous in a given layer, the whole collectively are considered as a *lode* by the miner, whether they occur in a schistose or granitic rock, as in the mines of Lanescot, and of Balleswhidden. In fact, these depositories of ore in slate are as well entitled to the name of *stockworks* as when situated in granite. So that, we have also veins of segregation in slate; and who can draw any line of demarcation between such veins, and the largest veins which have been explored by mining operations? or, indeed, even between the same description of veins which traverse both the granite and the slate at the junction of these rocks? Now according to the prevailing theory, veins cannot be contemporaneous when they intersect granite and slate, because these rocks are supposed to have been formed at different periods; and we have heard this circumstance used as an argument against the possibility of the vein being of such a nature; but surely this is not correct reasoning: the question is whether they are or are not contemporaneous, without any reference to the nature of the origin of the containing rock. We have frequently and carefully examined numerous parallel quartz-veins, running through both rocks, and differing from each other in size from a mere thread of a few inches in length, to a large lode extending beyond the limits of observation, but have not been able to detect any other distinction, all bearing the same relations to the containing rock, and exhibiting the same phenomena when interfered with by veins which have a different course. Even Mr. Carne, though he founds his distinction between true and contemporaneous veins on their difference of dimensions, observes, that some veins, which are very short, belong, perhaps, to the former order; and that others, of considerable length and width, to the latter. Since, therefore, the systematic characters of these orders are so indefinite, and since Nature does not appear to have made any discrimination between them, we think that we are justified in concluding that the veins which traverse the primary rocks are all of the same nature; and if so, it follows, that all are contemporaneous, since some are indisputably of this character. Thus furnishing another argument in addition to those already advanced, that the granite and the slate are likewise contemporaneous, being modifications of the same mass, only differing from each other in structure, the result of the same constituent particles variously aggregated.

In confirmation of this view, we will proceed to enquire whether the appearances of veins which are supposed to indicate a mechanical origin, furnish satisfactory evidence in support of this opinion.

True veins, or veins of fissure, as they are sometimes termed, are defined to be "the mineral contents of vertical or inclined fissures, nearly straight, and of indefinite length and depth."* This is Mr. Carne's definition; and, as far as we are aware, it has not been objected to by geologists: indeed, it accords with the idea long entertained, that veins were originally open fissures. In the first place, we object to this statement because the Cornish veins are never straight throughout their course, and their sides are never parallel for any considerable distance, since the veins are constantly varying in their width: for, as stated in the ninth chapter, veins undulate both in the direction of their course and descent, forming curves, which in general appear to be very irregular. That veins are very complicated in their course is proved by the fact that no inconsiderable skill is requisite in dialling; whereas, if they were nearly straight, this operation might be easily performed, if not dispensed with altogether. As regards the indefinite length and depth of veins,

* Geol. Trans. of Cornwall, vol. ii. p. 51.

we repeat that they do sometimes terminate; and although the miner often finds that veins which have tapered away into a mere string again expand into their original dimensions, yet they are not always worked to this conclusion; for, if they continue very small for some distance, they are generally abandoned: and that they are not of indefinite length may be inferred from the fact that the continuations of profitable veins, belonging to adjacent mines, have been sought for in vain within the limits of probable dislocations. Indeed, if veins were of this indefinite length, mining speculations would not be so precarious. If the term indefinite means any thing, true veins have no terminations: we will not, however, lay much stress on this point; and, perhaps, it was only meant to express that the extent of the length and depth has not been ascertained.

Again, it is said that veins were originally fissures; first, on account of the resemblance in their forms; and, secondly, because they contain mechanical deposits such as have been observed in actual fissures, now communicating with the surface. The noted case of Relistian mine has been often adduced as a proof of the latter; but we have already attempted to show that the masses of conglomerate enclosed in the lode are not of a fragmentary nature, but owe their peculiar appearance to a particular structure, not uncommon to some rocks, and which is participated in by a chlorite-schist in the vicinity of the lode. As regards the resemblance between the form of veins and fissures, this cannot be considered conclusive; if so, the spaces occupied by the small elongated portions of slate were also once fissures, as indeed even the strata themselves, for they might be equally compared with chasms such as are produced by earthquakes. On the supposition that veins were originally fissures, Cornwall must have been subject to innumerable convulsions: and in some districts, the total thickness of these openings must have borne no inconsiderable proportion to the whole mass. In St. Just, for instance, within a single mile, how numerous the parallel lodes are which have been worked; and these are few compared with those that have not been examined, and still more so with those veins that are not metalliferous. Now these parallel veins are supposed to be of the same age, and, being indefinite, they, of course, reach as far as Mount's Bay, a distance of seven miles; conceive, therefore, the comparatively narrow peninsula of the Land's End district, intersected by thousands of open fissures, inclined at a great angle, and yet the severed parts not falling together according to the known laws of gravity. But, perhaps, it may be argued that, although these veins belong to the same epoch, they were not absolutely co-existent as fissures, having been successively formed at various intervals during this period. Then we must fancy that convulsions followed each other for a certain space in one direction, and afterwards operated in other lines, in order to explain the position of the different series of parallel veins, described by Mr. Carne: but we will shortly endeavour to show, that the intricate interference of veins with each other cannot be easily reconciled with this notion.

We must not, however, leave this topic of fissures without noticing the nature of the union which subsists between veins and the containing rock, both as regards their respective structures and composition. It has been stated, in the ninth chapter, that large or true veins are often so situated as to occupy, as it were, spaces parallel with the joints or seams of the traversed rock; that is, they are parallel with one or other of the extended surfaces, resulting from the aggregation of similar concretions. We will not, however, from these facts venture on any generalisation, but repeat what we have already stated before the British Association, that the subject is worthy of careful consideration, in order to ascertain to what extent, and under what particular circumstances, this arrangement obtains.

The same condition is of very common occurrence on the small scale; for though the line of contact between veins and the rock, as between different kinds of rock, granite and slate, for instance, is often distinct, and marked by an open seam or joint, yet it is no less true that such a separation does not always exist, the vein and the rock forming individual concretions, in which both are firmly and intimately united: and this is best observed between the included portions of slate and the substance of the vein; as in such positions decomposition is not so energetic, the percolating water generally following the line of junction between veins and the main mass of rock.

Now it may be conceded, that fissures would probably be effected in the direction of one or other of the great lines of structure, in preference to a disruption of the solid rock: but it cannot be so readily allowed, that the substance of veins introduced into such fissures could unite with the already consolidated materials of the rocks, so as jointly to compose the same concretions; that is, that one portion of a concretion has been formed at one period, and another at a different time long subsequent to the former.

Concerning the composition of veins, if it be admitted that quartz, carbonate of lime, and some other minerals, can be introduced into veins in a state of solution; yet it will not, we presume, be supposed a possible event, that granite, slate, and other rocks could be deposited in fissures by a similar process: and yet the true veins of Cornwall generally contain no inconsiderable proportions of the adjacent rocks; and as these vary in nature, so do the rocky parts included in the veins, as well as the other mineral contents. Oh! but, say the advocates of the mechanical origin of veins, these portions of rocks are neither exudations nor depositions, but fragments detached from the adjacent mass, which explains their resemblance in composition. Can any one who has maintained such an opinion possibly have examined the position of these insulated portions of rock, or even reflected on their nature? for it appears to be a most self-evident proposition, that these pieces, whether detached during the disseverment of the solid rock, or during the violent injection of the matrix into the supposed fissures, would immediately fall to the bottom of the empty chasm, or subside through the injected fluid, whether igneous or aqueous, and not remain in positions which commonly correspond with the bearings of the adjoining mass. And let it be also remembered, that these insulated portions also abound in veins of various sizes, sometimes composed entirely of metallic minerals, and at others of quartz; at one time intersecting likewise the matrix of the large vein, and at another being blended therewith; and, moreover, these subordinate lodes (or *veins within veins*) exhibit all the phenomena of true veins, not even excepting those commonly referred to movements. How and when were such veins formed? When they occur in granite, they are called contemporaneous. According to the prevailing theory, however, this cannot be their origin, because the fragments of rocks, and the matrix of the vein, cannot be supposed to be of the same formation. How then could the different series of intersecting subordinate veins be produced? How could the successive fissures and injections be accomplished within the consolidated vein? These objections equally apply to all veins in rocks, which are known to terminate in length and depth, as indeed they would also to *true* veins, if we would only admit the analogy of the known to apply to the unknown limits, instead of concluding that the largest veins must be of indefinite depth, because they extend lower than 1500 feet below the surface; a measurement utterly insignificant compared with the probable thickness of the earth's crust, and therefore not an adequate datum for such a deduction. Analogy is surely, in this case, the safer guide of the two. We find veins descend to a certain depth, retaining their average breadth till they terminate; others continue their course lower than the deepest mines, but they likewise may not extend beyond limits, which may be of moderate dimensions compared with the diameter of the globe, though probably extending beyond the reach of mining operations.

It is time, however, to turn our attention to the intersection of lodes, a class of phenomena which has been more studied than any other on the subject of veins, and which is still considered to establish the axiom laid down at a very early period, *that a vein which traverses another is more recent than the one intersected.* Mr. Carne, in the paper already alluded to, has attempted, on this principle, to ascertain the relative ages of the Cornish veins, or rather we should say of the *true* veins; for his other two orders, the contemporaneous and doubtful, have not been included in this consideration. But we do not propose to walk in the same track, preferring our free and heterodox mode of enquiry, by bringing all kinds of veins, without any exception, to the test of this rule.

In the first place, contemporaneous veins, or veins of segregation, very frequently intersect each other, giving rise to the usual appearances of dislocations and displacements. This fact could not escape notice, and Mr. Carne attempts to explain it away, by asserting that " these phenomena are only apparent; as it is, *in general*, easy to perceive that what seem to be separate parts of the same vein, are different veins, which terminate at or near the cross vein." We would ask, do not the intersected portions of true veins often possess the same character? We are aware that the point in question has not been very extensively investigated, for the obvious reason, that the miner is not much interested in it; and such an examination, indeed, would be generally rendered very difficult, as the points of intersection are commonly obscured by a blending together of the matrices, and more especially by decomposition. The determination of this question is not at present very material, since it is admitted that this mark of distinction cannot *always* be detected in contemporaneous veins.

But how do these veins comport themselves, when they interfere with doubtful veins? When contemporaneous quartz-veins (that is, such as are short, crooked, and of irregular size) meet granite-veins, whether in granite or in slate, they are sometimes intersected thereby, at other times they are themselves traversed; and examples of both kinds may not only be seen within a few feet of each other, but if the granite-vein be branched, each ramification may be differently affected.

But granite-veins, whilst within granite, are said to be contemporaneous, but in slate, or when equally traversing both rocks, they are then *doubtful*. On this view, the contemporaneous quartz-veins are sometimes older and sometimes more recent than some granite-veins which are of the same age, or than others which are of doubtful origin: so that if there be any value in this principle, it involves the dilemma that the veins existed before the containing rocks, that the latter were broken and fissured previous to their formation. The same arguments apply to elvan-courses, for they are similarly circumstanced, as respects contemporaneous quartz-veins, both in granite and in slate. The prevailing opinion is, that granite-veins and dykes have been produced at every possible period since the protrusion of the granite; and that they are posterior to the stratified rocks in which they occur; but inasmuch as they are sometimes intersected by short, crooked quartz-veins which are as old as the slate, the latter must, according to the rule, be more recent than the igneous rock.

Again, what is the result of the intercourse of these quartz-veins with *true* veins? It is said "that they are always traversed by them," but we do not think that this generalisation has been deduced from observation; we rather incline to the opinion that it is of theoretical origin. Wherever small irregular veins are contiguous to large metalliferous veins, they are regarded as strings or branches; generally they are fairly entitled to this denomination; but we have seen the lesser veins extended into the substance of the larger, just as granite veins are often elongations of the mass, but sometimes continue their course through the granite in as distinct a manner as through the slate: such minute characters, however, are not very visible under ground, even when an object of research; but on the cliffs and on the sea-shore, they may be easily distinguished.

How are *doubtful* veins affected by true veins? Granite-veins are sometimes traversed by contemporaneous veins, and also by true veins, if it be admitted that the large quartz-vein, intersecting both granite and slate, at Mousehole, is a true vein,—and, if so, a parallel vein of the same nature is crossed by this granite vein at the distance of a few feet. Elvan-courses are commonly traversed by true veins: sometimes the latter are included in the former; but, in one instance, as at Polgooth, the elvan continues uninterruptedly through several metalliferous veins. The general opinion is that the elvans are veins of fissure, formed by igneous injections: Mr. Carne thinks that circumstances are in favour of their being true veins, and the miner sometimes considers them to be lodes;—the facts, however, already brought forward, render this very doubtful, since they both traverse and are intersected by contemporaneous as well as by true veins.

We now proceed to show that the relative ages of the subdivisions of true veins are of the same uncertain character as those of the *doubtful order*.

In the first place, it may be observed, that the application of the rule of intersection has led to the formation of several classes which seem to be very natural arrangements, inasmuch as they differ from each other either in composition, or in their bearings, or in both respects. Thus, the two first classes are *tin lodes;* the third, fourth, and sixth, *copper lodes;* the fifth class, *cross courses* or veins, not varying more than 30° from the north; the seventh, *cross flukans*, the same as the fifth, only entirely composed of clay; the eighth and last, *the slides*, of the same nature as the seventh, as regards composition and bearing.

Now the *tin lodes* are divided into two classes, because some are traversed and heaved by others; and they have been termed *the oldest* and the *more recent* tin lodes: the former are said to dip generally towards the north, the latter for the most part towards the south. But there is no general rule; indeed such veins, underlying to the same point of the compass at different angles, cause intersections; and, therefore, other classes ought to be instituted; —if, indeed, a character which can only be discovered by extensive workings, and is always subject to change, ought to be esteemed of any value in a classification. The directions of the tin lodes are commonly within a few points of east and west, but there are numerous exceptions: those of St. Just run nearly north and south, as does also one lode in Polgooth mine; and they must, therefore, be considered not as *tin lodes*, but as belonging to the class of *cross courses*. In Polgooth, also, occur veins of tin, pointing, not east and west, but north-west and south-east, and these *contra lodes* traverse and heave some regular east and west tin lodes; so that, according to the law of intersection, *contra lodes* are sometimes more ancient than the first class or the oldest true veins. We must, therefore, add to the present class of *tin lodes*, *contra*, *cross*, and as many other classes as there are exceptions. Besides, it may be stated, that veins in some parts contain copper ore, and in others, these minerals are intermixed with the tin; and since tin and copper lodes have the same bearings, how is the class to be determined when such veins do not interfere with those of an unmixed character?

In this manner, each of the classes might be considered in review, and without bringing forward other facts than those already on record, might be proved to be objectionable: thus, it might be stated, that the *more recent* are only separated from the *oldest* copper lodes, because *cross courses* are sometimes intersected by copper veins; if this additional class had not been instituted, the fifth and seventh classes would have been united; indeed, the last of these is not distinguished by the miner from cross courses; and these combined classes might also have comprised the eighth or *slides*, since they are only mineral veins which commonly run parallel with the metalliferous.

The only generalisations that can be made concerning the veins of Cornwall, in the present state of knowledge, are that they have various dimensions; that they cross each other in certain determinate directions; that they are composed either of solid earthy minerals, of ores, or of loose matter, such as clay or friable quartz (which are probably only the first in various stages of decomposition), some or all of which are frequently united in different proportions.

Having considered the nature of the intersection of veins as an indication of their having been formed at different times, we will next discuss the apparent movements by which these intersections are supposed to have been accompanied.

In the most simple form of such an occurrence, the prevailing opinion on this subject is very plausible, and seems to be confirmed by the fact, that in the mines, portions of the intersected vein have been observed to follow the side of the traversing one, so as to point out, as it were, the direction and the nature of the displacement: but, when we contemplate the curvatures, both in length and depth, of the supposed fissure, (now occupied by the substance of the cross vein,) the corresponding convexities and concavities of its opposite sides appear to be perfectly incompatible with such movements; for the fissure would have been obliterated thereby, in many parts where the vein now possesses its full dimensions. Now, as regards the indications of ore along the cross vein, intermediate between the discontinuous veins, we do not, on the supposition of both being contemporaneous, think it an unwarrantable conjecture, that the power of cohesion, electro-magnetism, or whatever force governed their arrangement, should have left at the points of interference some traces of the joint action of the intersecting currents. However, be this as it may, how can we surmount the difficulty, that one vein crossing another, without any movement in one place, in others at different depths, produces heaves of various extent, and *vice versâ*, as in Dolcoath mine?

When more complicated instances of intersection are examined, the imperfection of the theory is still more evident:

for instance, when one vein crosses several others, which are of the same denomination. At Mousehole, two granite veins, of no inconsiderable length and regularity, are heaved by a quartz-vein; one to the distance of three feet, but the other not more than six inches; and this happens within a few feet of each other: how could one part of the rock be moved farther than the other? or, how could any displacement happen? for not many yards off the quartz vein terminates, and the joints of the slate continue without any derangement across the direction of the vein. The intersections of small contemporaneous veins, however minute, frequently afford similar examples; and in the case of large veins, such as are explored in mining operations, this condition of the various disconnected parts is so common, that we need only refer to the instances already quoted in the ninth chapter. Nor must we omit to remark that if the lines dividing the layers or laminæ of rocks be closely inspected, they will sometimes, especially when the rocks consist of alternating layers of different composition or colour, seem to be heaved either with or without the intervention of veins of any description: the opposite layers, however, have not always the same dimensions; or, as in the instance of gneiss traversed by a quartz-vein, in Fudia, described by Macculloch, the laminæ are heaved by the latter as far as it extends, but immediately beyond they are not disconnected.* Lastly, veins exhibit the same apparent phenomena of motion without the presence of cross veins or fissures, as in Balnoon mine: and the laminæ of rocks likewise afford analogous appearances, as in the gneiss of the Island of Lewis, also described by the geologist just quoted.† Granite-veins, whether of different composition or not, and even the crystalline ingredients of many rocks, also interfere with each other in every possible manner, so as to give representations of all the phenomena of metalliferous veins.

* Western Islands of Scotland, Plate xi. fig. 3.

† Idem, Plate xvi. fig. 5.

In concluding our remarks on this important subject, we venture to express a hope that if the objections advanced are not altogether unanswerable, yet, that they are of sufficient weight to prove that the apparent movements which the primary rocks are supposed to have undergone, are not established on a satisfactory basis: since it cannot be admitted that the curvatures and convolutions of their laminæ and beds, their occasionally brecciated and conglomerated structure, their elongated masses in the form of rock-veins, and, lastly, their mineral and metalliferous veins, do furnish physical evidence of mechanical movements; for such appearances, in most instances, if not in all, may have originated from peculiar modes of arrangement during the aggregation of the constituent particles of the primary rocks.

CHAPTER XVI.

MAY NOT ALL THE PHENOMENA OF THE PRIMARY ROCKS, BOTH STRATIFIED AND UNSTRATIFIED, BE SATISFACTORILY EXPLAINED ON THE SUPPOSITION THAT THESE ROCKS ARE OF CONTEMPORANEOUS ORIGIN?

Recapitulation of the principal facts, and of the conclusions deduced therefrom. — The primary slates not sedimentary deposits — are in their original positions — their contortions, fragment-like structure, and veins, no indications of violence — not derived from the metamorphoses of fossiliferous strata. — The prevailing theory not founded on a correct deduction from facts. — Another explanation of the phenomena of the primary rocks offered — its consistency with the general opinions concerning the nature of the secondary and tertiary formations. — Conclusion.

In the preceding chapters we have advanced objections against various opinions which are generally entertained concerning the nature of the primary rocks; and we have, at each step, successively concluded that the phenomena which were under consideration might receive a more plausible solution, by supposing them to have been coeval with the formation of these rocks.

It is now proposed to show that these several conclusions are consistent with each other, and that the theory of the primary rocks, resulting from their combination, may be conjoined with that of the secondary and tertiary formations which now prevails, and which has been deduced from a comparison of their phenomena with analogous appearances, produced by causes now in operation. But, before entering on these considerations, it is desirable to recapitulate the objections which have been brought forward, and the leading arguments by which they have been supported, in order to bring the matter into as small a compass as possible, so as to render the nature of the dissent more evident.

In the first place, it is contended that the primary slates are not stratified, if it be thereby understood that they consist of sedimentary beds arranged by the agency of water after the manner of the fossiliferous deposits. The analogy between the arrangement of the beds, and of the laminæ, in the rocks of both formations, is not disputed; but it has been argued that it furnishes no evidence that the primary slates are of a mechanical or aqueous origin, since not only granite, but also trap, and even lava, present the same appearances:—in short, we maintain that arrangements which only mark the varieties of concretionary structure produced during the consolidation of the once mobile particles of rock, and which do not characterise any particular formation, cannot be admitted to prove that the primary slates were originally sedimentary deposits.

Since, therefore, the supposed indications of stratification are as applicable to granite as to the crystalline slates with which it is associated, it might be inferred that this unstratified rock is also stratified, and that the generally esteemed igneous rock is of aqueous origin. How can this dilemma be avoided? Are there any other characters, common to the so called primary strata and the fossiliferous groups, by which they may be distinguished in all cases from the granitic rocks? The form and structure of beds, and the alternations of rocks varying in mineral composition, as already stated, do not afford any criterion; nor can we adopt the transitions between these two classes of strata as evidence of the primary slates being stratified, and of aqueous origin, for these again are connected with granite by a more complete bond of union, by that kind of transition which we have called the mineral, in order to keep it distinct from the mechanical, which obtains in the former case.

A lengthened consideration of these difficulties has led us to infer that the prevailing classification, which divides rocks into the stratified and unstratified is very inaccurate, and more especially so since the term stratum has not been hitherto satisfactorily defined.

Again, we have objected on various grounds to the opinion that all inclined strata, and particularly the primary, were originally horizontal: — 1. Because, with the exception of those secondary strata, which contain tubulites and similar fossils, the evidence in favour of such elevations is neither so decisive nor so copious as to warrant a general conclusion: on the contrary, we know that rocks are deposited in beds which are inclined at considerable angles; and that, when this happens, the beds are also fan or wedge shaped, being wider at their lower than their upper extremities, so that each succeeding bed, in the ascending order, becomes less and less sloped, until the cavity or hollow, in which the deposits were formed, is partially or even entirely obliterated; a mode of arrangement which has its exact counterpart both in the secondary and tertiary formations, as has been observed in numerous instances in almost every country, but which, hitherto, has not been distinctly and unequivocally detected in the primary slates. 2. We also dissent from this opinion, because beds may not only be originally deposited in inclined positions, the limits of which have not been yet ascertained, but because the layers of rocks attributable to their concretionary structure, which are, for the most part, placed at great angles, have evidently been often considered as strata in the fossiliferous, and always in the primary formations; and, in the case of the latter, such beds have been described as dipping various ways, and as being sometimes parallel with the laminæ and at other times differently inclined, in consequence of the mass being composed of several concretionary layers. Now, numerous examples have been adduced to show that such inclined layers, whether laminæ or beds, are not confined to the primary slates; but that they actually occur in every group of sedimentary rocks, whether these consist of pebbles, sand, mud, and similar mechanical deposits, or of precipitates from a state of chemical solution; and moreover, that they are also occasionally present in granite, trap, lava, and analogous rocks: facts which demonstrate that the so-called strata have not derived their inclined positions from elevation: and when to these instances are added those beds admitted to have been formed on inclined planes, there is a great preponderance of evidence against the generally received opinion that strata were originally horizontal and have been subsequently tilted up by some internal moving power. 3. We cannot subscribe to this doctrine of elevation, because the protrusion of granite, the supposed cause of such movements of the strata, is not justified by any known analogy. The internal fire, the *primum mobile* of all the commotions and derangements of the solid crust of the earth, appears to be adequate to the upraising of vast tracts of country, but this is effected without altering the previous position of the various rocks and unconsolidated deposits. It causes fissures and chasms in the superimposed rocks, through which it forces aërial fluids, lava in a state of fusion, fragments of rocks, mineral substances, and other kinds of volcanic ejecta, which arrange themselves around the apertures so as to form conical hills or mountains composed of highly inclined and irregularly concentric layers. But in none of these cases have any appearances been observed which indisputably establish such elevations of the strata as are now the subject of consideration. And even granting that granite has been so protruded, such an elevation could not have been effected without causing fissures through the incumbent strata; for even the comparatively small effects of actual volcanic operations, which are unattended by local tiltings up of the beds, produce such openings: and if this were the case, how could the adjacent strata have escaped total destruction? for immediately the expansion overcame the resistance, a dreadful explosion must have inevitably followed. It may perhaps be argued, that the strata, when thus upheaved, were in a ductile state, in consequence either of their being intensely ignited, or of their not having been as yet consolidated: but such an opinion, however well adapted to remove one difficulty, falls into another; for it is opposed to the phenomena exhibited at the junction of granite and slate, and which, even Sir James Hall has allowed, indicate "an infusion of the liquid granite into hard and brittle strata." And we have attempted to show that the protrusion of this rock in a solid state is not only unsupported by analogy, but is at variance with the nature and arrangement of the granite and schistose rocks at their junction. On these grounds, therefore, we think that the theory of the elevation of strata by granite is not founded on correct and certain data: indeed, inasmuch as the nature of the term stratum is indefinite, and has been applied in an indiscriminate manner to very different kinds of beds, even by the same observer, no evidence concerning the direction and dip of strata can be esteemed, until it be determined in what sense the term has been employed. We have stated our reasons for not adopting Elie de Beaumont's theory concerning the relative ages of mountain chains: nothing farther, however, need here be added, since many of the most eminent geologists have proved that it is not in accordance with the phenomena of inclined strata in different countries.

In examining the other appearances of the primary rocks, which have been commonly referred to various movements, we have expressed an opinion that they are fallacious, and more easily explained on the supposition of their being contemporaneous with the formation of the rocks in which they occur. We disagree with the general opinion, for the following reasons: — 1. As regards the convolution of rocks; because contorted beds alternate with other beds which are plain and regular; because the laminæ of rocks are also similarly circumstanced; because the colouring ingredients of rocks, whether on a large scale, as in strata, or on a small, as in laminæ, are likewise subject to the same arrangement; and, lastly, because granite and trap, travertin and other aqueous deposits, and agates and alabaster, also exhibit the most complicated curvatures and contortions, in all of which the indications of forcible bendings can only be apparent. 2. Concerning the rounded and angular fragment-like portions of rock which occur in some members of the primary formation, we think them very different from some similar occurrences among the derivative rocks, but not from all; for they sometimes, like the primary, are to be attributed to concretionary structure, resulting from the peculiar manner in which their component parts were aggregated; and in such cases the apparent fragments are always more or less intimately united with the bases by mineral transitions, or possess such frail and delicate forms as are not consistent with their supposed previous attrition; both of which circumstances are very dissimilar to the ordinary condition of the nodules and fragments of true conglomerates and breccia. 3. We object to the supposition that granite veins were originally fissures subsequently filled by the injection of granite in a state of fusion on several grounds, but principally on three, relating to their structure, composition, and interference with other veins. In form they are very seldom regular, as cracks or fissures generally are, but present an endless variety, both as regards their size and direction, and intersect each other, in the most promiscuous manner; and, when sufficiently large to exhibit a concretionary structure, the lines by which this is denoted sometimes correspond with the sides of these veins; but often, as at the junctions of granite and slate, indiscriminately involve a larger or smaller proportion of the adjacent rock. In composition, they always partake more or less of the nature of the intersected granite or slate, including portions of these rocks in their course, with which, as well as with their main mass, they are frequently united, by the most perfect mineral transitions; and this is not only the case, but the prophyritic crystals, whether of felspar or hornblende, contained in the main mass or substance of the veins, are sometimes arranged across the line of junction, so as to be common both to the vein and containing rock; a bond of connection, which has also been observed at the meeting of granite and slate, and which some may attempt to explain, by attributing it to the metamorphic period, when both rocks were in a state of complete or semi-fusion: but such a solution cannot be extended to granite-veins, which, according to the established theory, were injected into hard rocks, capable of being fractured, and of furnishing small angular fragments. Lastly, in their interference with other veins, they intersect, and are themselves intersected by, quartz-veins, which possess both true and contemporaneous characters: thus indicating, according to the axiom, "that a vein which traverses another is more recent than the one intersected;" that granite-veins have not only been introduced into the containing rocks, but also existed prior to their formation. 4. Concerning the mineral veins, which occur in primary rocks, we contend that, so far from the present state of our knowledge on this subject being sufficiently advanced to justify any theory, it is so very imperfect, that we have not even accurate descriptions of the objects themselves, the very elements on which the generalisation ought to be founded: and we have adduced numerous, and several of them new, facts, to show that, if any opinion be permitted, that of their contemporaneous origin is the more plausible. That mineral veins cannot be defined to be the contents of fissures, we have attempted to establish by the following objections: — 1. No line of distinction can be drawn between veins of segregation and true veins, the former of which are said to be coeval with the consolidation of the traversed rock, and are admitted to characterise some of the metalliferous veins of Cornwall. Nor can we discriminate between large and small veins, or such as are supposed to be indefinite in extent, and those which are entirely comprised within the limits of our observation; that is, between the commonly called true and contemporaneous veins. 2. As regards the origin of true veins in fissures, we contend that such variously inclined cracks and chasms, extending for considerable lengths and depths, are incompatible with the laws of gravity; that the great contortions of veins are not consonant with the usual forms of fractures; and that the portions of rocks, similar to the adjacent mass, which are included within the quartzoze substance or matrix of these veins, and which are often of great size, and arranged conformably with the adjacent strata, could not be maintained in such positions, within either empty fissures, or in the midst of igneous injections, but would fall to the sides of the veins, or even to their bottom, far below the present limits of mining operations. 3. The nature of their composition, and the mode of their connection with the adjacent rocks, both by mineral transitions, and a community of concretional structure, are facts which do not indicate the introduction of foreign and heterogeneous substances into fissures; and such an origin is rendered still more problematical, by the occurrence of subordinate veins in large lodes, or what has been termed *veins within veins;* for how could fissures be formed and filled in such situations, and not only in the matrix, but also continuously through the consolidated portions of rocks? and moreover, under such circumstances, how could these lesser veins exhibit all the phenomena of intersecting lodes? 4. We do not subscribe to the axiom just quoted concerning the relative ages of veins as indicated by intersection; because every description of veins, whether segregated, contemporaneous, or true, presents precisely the same appearances: this, in the second instance, has been asserted to be fallacious, but we have disputed the correctness of this view of the case at some length. Moreover, the different *orders* of veins interfere with each other in like manner, by which it seems to be proved that they are all of the same nature. Lastly, the division of true veins into classes of different ages cannot be maintained, for each class affords exceptions; and not only so, but even the relative age of two veins, as in Dolcoath, may be inferred to be of a certain denomination in one part of the mine, and of a very different one in the other; because, at a given level, A traverses B, and at another, B is the intersecting vein. 5. Although the *heaves* and *throws* of veins appear at first sight to confirm the mechanical origin of these bodies, yet they will not stand the test of a rigid scrutiny; for of whatever kind the veins may be, when several are traversed by one vein, the extent of the apparent movement is in general not uniform, and sometimes varies in the case of each individual vein: and it may be likewise added, that similar phenomena occur not only in veins, but also in the strata and laminæ of rocks, when no cross vein, or even fissure, can be detected.

Finally, we have advanced objections to the theory concerning the metamorphosis of sedimentary deposits into crystalline or primary slates. 1. We have expressed some doubts whether the transitions which have been observed between these rocks, can be regarded as a criterion of identity; because, on this principle, the secondary and tertiary formations might be referred to the same epoch, and even granite, gneiss, and similar rocks might be confounded with adjacent conglomerates which are composed of their detritus: and it has been attempted to illustrate the fallacy of such transitions being considered as evidence of coeval formation, by the occurrence of beds of transported debris on the shores of Mount's Bay, which may, by such means, although overlying sand containing sea-shells, and a stratum of decayed wood or a submarine forest, be proved to be identical with the primary slates; or, in other words, the latter would be demonstrated to be the metamorphic strata of sedimentary deposits, belonging to the modern geological epoch. 2. The facts by which the advocates of the Plutonic theory have attempted to prove the power of fire to convert secondary strata into primary, have been passed in review; the effects of trap-rocks on sedimentary deposits have been compared therewith; and then we have attempted to show, by referring to chemical analyses, that, with the exception of dolomite, and perhaps of porcelain-jasper and of analcime, the nature of which seems to be doubtful, all these changes are such as may be attributed to a mechanical alteration of the structure of these rocks, resulting from a partial state of fusion. Whilst the primary slates next granite not only exhibit similar appearances, but differ from the more remote portions of these rocks in their chemical composition, which, if indicative of any alteration, points to the transmutation of one earth into another; such as that of alumina, or of lime, into silica. But this is not the only difficulty; for all the primary strata, excepting occasional pure beds of limestone and quartz-rock, if there be such, contain some alkali which does not exist in the sedimentary rocks: and many arguments have been brought forward to prove that the alkalies could not have been introduced by the granite; for if so, it must have traversed some beds, without entering into combination therewith, though these occasionally consist of quartz, which, according to theory, must have been in a state of ignition. The principles of chemistry do not form the only grounds of objection to the so-termed metamorphoses, for these are also at variance with the laws of caloric: for how can it be conceived that heat could be so transmitted through such a vast extent of non-conducting beds of clay and sand, as to produce its greatest effects at a considerable distance from its source, without bringing the nearest beds into a state of perfect fusion, or, indeed, without causing any, or but very little alteration in several intermediate strata?

Such are the principal objections which, in the preceding chapters, we have advanced against the prevailing theory, and we venture to express a hope that they will be deemed sufficiently important to obtain a candid and patient examination.

For these various considerations, we therefore conceive that the prevailing theory is not in accordance with the phenomena of the primary rocks, and that it is not founded on a full and fair deduction from facts. We are informed that the modern or improved method of theorising "seeks an interpretation of geological monuments by comparing the changes, of which they give evidence, with the vicissitudes now in progress, or *which may be* in progress."* But the earlier enquirers (remarks the same author whom we have just quoted) employed themselves in conjecturing what might have been the course of nature at a remote period, rather than in investigating what was the course of nature in their own times. Indeed, of late years, notwithstanding the repeated warnings of experience, the ancient method of philosophising has not been materially modified. " In our attempt, however," says Lyell, " to unravel difficult questions, we shall adopt a different course, restricting ourselves to the known or possible operations of existing causes."

We have been induced to make these extracts for two reasons; first, in order to vindicate the character of the earlier enquirers; and, secondly, to show that the Professor himself is a disciple of the ancient philosophy of which he has expressed his disapprobation. That the speculations of geologists, formerly, were entirely imaginary, cannot, we think, be maintained: it is true that they were not founded on such extensive data of the known effects of natural agents as they now are, but they always had some reference to actual operations, though these were frequently but very imperfctly understood. But surely it is not fair to consider their intellectual exertions inferior to our own, by a comparison instituted between the dawning twilight of the science, and the present time, when the whole horizon is illuminated by copious and brilliant rays of light: succeeding enquirers will possess a more extended knowledge of nature, and probably a more perfect mode of investigation than ourselves, but they must not on that account suppose that our science was not founded on the same rules of induction, though often misapplied, and sometimes extended beyond their legitimate limits. In the same manner, Lyell has (as we conceive) carried the analogy of the operations now in progress too far, in supposing that

* Principles of Geology, vol. iii. p. 3.

all the phenomena of the primary rocks, or, indeed, of the secondary, can receive thereby a satisfactory solution. As regards the application of this rule to the tertiary rocks, he appears to have been eminently successful; but when he touches on the department of the science which forms the subject of this work, his speculations seem to us to be as fanciful as those of the earlier geologists. The Neptunian speculations, originally suggested by the observed effects of aqueous agents, were pushed, he says, beyond the limits of analogy: an observation which seems to apply also to the modern Plutonic theory, since he has admitted that "nothing strictly analogous to the primary rocks can now be seen in the progress of formation on the habitable surface of the earth, —nothing, at least, within the range of human observation." * This being the case, we think that, after the numerous objections which have been advanced against this theory, we are justified in our dissent from speculations which are not supported by analogy, and will not account for all the phenomena; and we may, perhaps, be permitted to attempt their explanation in a different manner, and to show how this may be conjoined with the prevailing opinions.

It has been already stated, that the result of the preceding enquiry has led us to conclude that the primary rocks, both granitic and schistose, are of contemporaneous origin, only differing from each other in their component parts being so aggregated as to produce different kinds of structure. We do not contend that any particular agent, whether fire or water, has formed these rocks; as it is immaterial to our views, how the fluidity of the mass was originally accomplished, provided its particles had such a degree of mobility as would permit their regular and elective arrangements. But as the general opinion inclines to the adoption of fire as the grand primeval cause which prevailed over all others previous to the consolidation of the earth's crust; and as it appears to be

* Principles of Geology, vol. iii. p. 11.

rendered probable by the phenomena of volcanos, the high temperature of deep mines and of mineral springs, supported moreover by the approval of some eminent astronomers, it may be adopted as the first step towards the erection of a theory of the earth.

At this stage of the speculation, we might indulge in various fancies, as to the precise order and mode of consolidation, and as to the condition of the aërial and aqueous fluids during the secular refrigeration of the surface of the igneous mass. We have, however, been anticipated therein, by French as well as by British geologists; and though we might suggest some modifications of their views, yet we prefer commencing at the period when the exterior of the earth was so far solidified and reduced in temperature, as to admit of the combined co-operation of igneous, aqueous, and atmospheric agencies, similar to those which now modify the form and condition of the superficial parts of our planet.

At this early period in the history of the earth, we conceive that all the rocks belonged to that class, commonly called primary, which has been the subject of our consideration; — that is, they were not all granitic, as is generally supposed, but also schistose; both kinds being intermixed, sometimes the one and sometimes the other predominating in certain portions of the earth, and associated together under precisely the same arrangements as those now observed in the primary formations. On this view of the contemporaneous origin of the granitic and schistose rocks, we may easily comprehend numerous phenomena which appear to be exceedingly complicated, on the supposition of these rocks being of distinct and diverse natures—the one of igneous and the other of aqueous derivation. Thus, if the various kinds of granite and schist were formed at the same time, they might be expected during consolidation to assume similar concretionary structures. And it is, therefore, not surprising that the layers or beds resulting from the extensive aggregation of such concretions, should often pass through both rocks, or be arranged, side by side, in a regular and conformable order, as at the junction of large masses of these rocks, or, in the case of their association, in lesser or alternating beds; nor, that the individual concretions should frequently contain both rocks in different proportions, and yet exhibit a distinct line of junction, as denoted by the colour or the texture of each mineral compound: for since the various parts of the whole mass graduate into each other, it can be easily imagined that the elective chemical attractions which regulated the combinations of the particles of the cooling fluid mass, might be independent of the mechanical attractions of cohesion, by which the concretions were formed during its consolidation. Again, as regards the internal structure of these rocks, we have seen that it may be either compact or schistose, in all without exception; though the former prevails in some places and the latter in others: these kinds of structure can, therefore, only be considered as specific, not as generic distinctions: and much less as indications of different modes of formation, affording a proper basis for the division of rocks into the stratified and unstratified classes. We have, elsewhere, attempted to illustrate this subject by referring to the structure of an ingot of bismuth, which has been allowed to cool very slowly from a state of fusion; it exhibits clusters of crystals, both rectangular prisms and octahedrons, surrounded by foliated laminæ; affording a striking representation of the formation of the massive and schistose structures in one and the same mass, and that too in a simple elementary substance.

When we descend to the composition of the granitic and schistose rocks it will be found to furnish additional evidence of their contemporiety. Thus, each group of these rocks shows that all its members, however dissimilar in their appearance, repeatedly pass into each other by the most insensible gradations; and not only so, but these groups have the same relations, wherever they meet together. This character is so strongly marked, that even *stratified* limestone, where it joins granite, as at Glen Tilt, partially loses its fissile structure, and becomes very siliceous, the granite at the same time being very quartzose; and when a crystalline schist has a granular texture, and meets with a fine-grained porphyritic granite, so as to render the junction apparently abrupt; then large crystals of felspar traversing both rocks have occurred, removing all doubt as to their identity. And this view of the primary rocks is farther confirmed, by the numerous instances that have been recorded, concerning the coincident composition of adjacent granitic and schistose groups; an agreement which has not only been observed in several countries, but also, in various parts of the hornblendic, shorlaceous, talcose, and other formations.

And lastly, the structure, composition, and modes of union with the containing rocks, render it exceedingly probable that the conglomerated and brecciated concretions, and the granitic and mineral veins, are not of mechanical origin, but have been formed during the cooling and consolidation of the primary igneous mass. To recapitulate the evidence in favour of this opinion is not necessary, since it may be readily gathered from the last chapter, or may be deduced from the objections enumerated in this against the prevailing opinion.

Such, we presume, was the condition of the primary rocks at the time of their formation from the refrigerating igneous mass, and when the causes now in operation were first called into action. It may, perhaps, be deemed incumbent on us to explain how the bearings of strata, of beds or courses of granitic rocks, and of veins, always exhibit, in certain localities, a considerable degree of regularity, which the prevailing theory attributes to the expansive power of the internal fire fracturing and elevating the strata, in various but determinate directions. It appears to us that these conditions of the primary rocks have been effected by the same influence as that which caused the laminæ diagonally arranged within strata, and contemporaneous veins, to assume certain positions; occurrences which cannot be supposed to have originated in the application of any extraneous force. Is it not within the bounds of probability that the chemical union of the elements of the fused mass, whence resulted such a vast body of definite minerals, should be accompanied by the evolution of numerous currents of electricity, or of analogous fluids? for we know that the oscillations of the particles of matter, whether produced mechanically, or during chemical combinations, will elicit streams both of common and galvanic electricity. If, then, it be acceded that the primary rocks may have been traversed by such currents during their formation, we have an explanation of the regular disposition of the granitic rocks, of veins, and of other crystalline substances; and, indeed, not only of the subordinate parts, but also of the entire mass.

This idea will remind the reader of Mr. R. W. Fox's experiments, from which he has concluded that the Cornish metalliferous veins were formed by electro-magnetism. By such imaginary currents, crossing each other in different directions, we also fancy that the phenomena of intersecting veins might be accounted for, the more powerful ones having uninterruptedly continued their course, whilst the weaker ones experienced various degrees of diversion, being either partially or altogether involved in the impetus of their stronger opponents. But whether the bearings of the beds and veins of the primary mass originated from this source, or from any innate disposition of the constituent particles of its minerals to affect certain lines of combination, will probably remain a mystery for many ages; but the time may possibly come, when, by accumulated experience, circumstances which are now inexplicable may receive a more rational solution. At present, however, we cannot obtain any certain knowledge concerning the formation of the earth, earlier than that epoch when the granitic and their associated schistose groups existed, and furnished, through the operation of causes similar to those now in action, the materials of which the oldest derivative rocks are constituted. These groups are, therefore, fairly entitled, if this view be correct, to the appellation of *primary*, since they appear to have been formed before all rocks which are analogous to modern productions. Notwithstanding, it would be preferable to adopt, in place of the term primary, some other, not conveying a theoretical signification; for even that of granitiferous, which we have sometimes used, is not entirely free from objection, since some intrusive porphyries and traps mineralogically resemble the granitic rocks.

Having stated our conjectures concerning the primary formations in their original condition, we now proceed to point out in what manner they may be conjoined with the prevailing theory concerning those rocks which have been subsequently formed.

The primary rocks, at the earliest period of the existing order of things on the earth's surface, appear to have been subject to the chemical and mechanical actions of the elements: by the former of which they have been, to a certain extent, successively decomposed and disintegrated; and by the latter, degraded and converted into gravel, sand, clay, and like incoherent substances, capable of being transported into new localities.

Such deposits have been derived from the primary rocks during every geological epoch, but not always in the same ratio, inasmuch as they have gradually covered up and protected these rocks from the elements, and have in their turn become exposed to the same destructive influence; and thus it is, that recent transported deposits are seldom of an unmixed character, being wholly composed of the debris of primary rocks only in their immediate vicinity. In like manner, also, newer deposits are conjoined with the granite at the surface, either covering older ones or immediately resting on the primary rock: — the precise order of these depositions depends on the combination of various circumstances; among the most important of which may be enumerated, the relative levels of sea and land, previous to and succeeding such formations, the degree of power possessed by the transporting agent, and the form and position of the surfaces on which the deposits took place.

Such successive masses of transported debris have been observed in every geological group, and appear to have been produced by extraordinary movements of water, occurring at distinct and remote periods, and which have been termed diluvial currents, or débâcles. These catastrophes are now disputed, the ordinary operations of water being deemed adequate to explain all the phenomena. Let us, however, try this opinion by applying it to the recent deposits resting on the primary rocks of Cornwall; and they are well adapted for this purpose, because their materials may be traced to the parent rocks, which form the more elevated parts of the country. Rivers could not have brought down these beds of debris, because the extent of land between them and the summits of the hills is only sufficient to produce small rivulets; the bursting of lakes could not be their cause, since the form of the surface is not in favour of such a view, nor to the collection of large bodies of water; the waves of the sea could not be the agent, because the deposits often rest on vegetable strata, the remains of trees and plants, which actually flourished on the places where they now repose. Perhaps it may be argued that they were formed during the emerging of the land from the ocean: if this be admitted, then Cornwall has thrice subsided, and again arisen above the water, and acquired a different sea-level at each catastrophe. But even such operations are surely abnormal, differing much from the constant and ordinary action of the sea; and we are only desirous of establishing that water, as a transporting power, has periodically acted with extraordinary violence.

Now, between these débâcles, we conceive that there were successive periods of comparative rest, in which the ordinary changes were gradually progressive. Thus, wherever solid rocks or loose deposits were exposed, atmospheric and aqueous degradations would be effected according to their situations: their general surface, however, would be protected; the dry land by vegetation; marshy places by the conjoint action of plants and sediments; the hollows, containing lakes, by deposits, mixed with organic remains; the bottom of the sea by the accumulation of gravel, sand, and marine productions. Since, therefore, these various occurrences, in each geological epoch, are contemporaneous, it is evident that vegetable, lacustrine, marine, and other formations may be the equivalents of each other, though greatly differing in nature: and, as one and the same district may exhibit all these formations, even resting on the same rock or *diluvial* deposit, so each of these, confined to an extensive tract or country, owing to its being entirely situated above or below the sea-level, would be parallel or equivalent to the others, although one would be characterised by terrestrial, another by lacustrine, and the third by marine organic remains.

This is a most important consideration, for it teaches us that we must not only become acquainted with the order of succession, in which the various families of plants and animals appear to have been called into existence, but we must also determine the precise genera and species of land and of fresh and salt water animals and vegetables, which flourished during the same geological epoch.

The frequent intermixture of all kinds of deposits, in the same group, will, perhaps, ultimately lead to the full developement of organic equivalents; and then the uncertainty concerning the analogy of remote series of rocks, which at present perplexes geologists, will be greatly diminished. This task, however, cannot be speedily accomplished; indeed, even the animated beings peculiar to every climate, and to various situations in the same country, during the modern or present epoch, have not as yet been ascertained.

As regards the igneous or volcanic power, the remaining cause of changes now in progress, we may presume that it has been active, from the period of the formation of the primary rocks to the present time. It is very possible that, during the consolidation of these rocks, dykes and veins may have been formed, like those of lava in the cones of volcanos. But the cases appear to be very dissimilar; one of these is the effect of violent injections and protrusions, the other is supposed to have arisen from the gradual refrigeration of a fluid mass: and, besides, we have not been able to detect in the primary rocks any indication of such occurrences. We will, therefore, as during the consideration of atmospheric and aqueous causes, begin at the epoch when the formation of the oldest detrital deposits commenced. From that time, different parts of the surface of the earth have experienced successive alterations in the relative levels of sea and land, which may be fairly referred to the expansive force of the internal fire, since similar phenomena have been observed in volcanic countries. During each geological epoch, volcanos appear also to have existed: and that they communicate with or even below the primary rocks, is rendered very probable by the ejection of fragments of such rocks; by their cones in some instances reposing on granite; and, lastly, by the composition of lava, trap, basalt, and similar substances, which contain a portion of alkali, and which may therefore have been derived from the same source as the primary rocks. Lastly, each sedimentary group is traversed by dykes and various masses of crystalline and alkaliferous rocks, which possess all the characters of an igneous origin: these rocks in the oldest deposits often resemble the primary, both in composition and in external and internal properties, and can only be distinguished therefrom by their geological position and mode of union with the adjacent schistose rocks. Whether such dykes or intrusive igneous rocks do actually occur in the primary at great depths, or whether they have traversed every part thereof during each sedimentary epoch, is a question which our present knowledge does not enable us to determine. The primary igneous rocks may be so circumstanced with respect to the intrusive ones; and such a condition would not be incompatible with the hypothesis which considers granite, and its associated schists, to have been contemporaneously formed before the existence of the fossiliferous strata: but we think it better not to admit this until it is clearly demonstrated.

Having thus briefly stated our notion concerning the formation of the earth, and having pointed out in what manner this conjecture, although opposed to part of the prevailing theory concerning the primary rocks, may yet be combined with the general opinion regarding the nature of the secondary and tertiary formations, it only remains to apologise for thus obtruding another hypothesis into a science which is already overburdened with speculations.

We might plead, in extenuation of our conduct, the very general bias to theorise in those who have been zealous cultivators of geology; but we think that we have a better excuse in the necessity of our case; for we felt it incumbent on us, after such strenuous exertions to overturn the Plutonic theory, to offer another explanation of the perplexing facts. Indeed, if we had not attempted to supply the deficiency, it might be observed, in the event of our success, that an imperfect theory is better than none. We were also urged onwards in this course by other cogent motives—the assurance that it would tend to render the work more complete, by throwing additional light on the nature of our dissent, and the sanguine hope that, by pointing out a different view of the subject, without perverting any known analogies, we might more readily induce a conviction that the phenomena of the primary rocks are not in accordance with the prevailing theory.

We sincerely trust, however, whatever may be the issue of the approaching discussion, that, as fellow-labourers in a common cause, we shall be actuated by a mutual esteem, and only strive, in friendly competition, who can render the best interpretation of the great and glorious mysteries of Nature.

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